Washington State Department of Transportation

SR 166 MP 4.52 Olney Creek (15.0201 0.90):

Preliminary Hydraulic Design Report

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Abbreviations

°F	degree(s) Fahrenheit
2D	two-dimensional
BFW	bankfull width
cfs	cubic foot/feet per second
DNR	Department of Natural Resources
DPS	distinct population segment
DS	downstream
ESA	Endangered Species Act
ESO	Environmental Services Office
FEMA	Federal Emergency Management Agency
FHD	Final Hydraulic Design
FIRM	Flood Insurance Rate Map
FPW	flood-prone width
ft	foot/feet
ft/s	foot/feet per second
FUR	floodplain utilization ratio
GIS	geographic information system
HDR	HDR Engineering, Inc.
H:V	horizontal:vertical
ID	identifier
in	inch(es)
lb	pound(s)
LF	linear foot/feet
LiDAR	light detecting and ranging
LOB	left overbank
LWM	large woody material
MP	milepost
MRI	mean recurrence interval
NA	not applicable
NAVD88	North American Vertical Datum of 1988
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
OPSW	Olympic Peninsula and Southwest Counties
PEO	Project Engineer's Office
PHD	Preliminary Hydraulic Design
ROB	right overbank
SF	square foot/feet
SFHA	special flood hazard area
SR	State Route
STA	station
SWIFD	Statewide Washington Integrated Fish Distribution
US	upstream
USBR	United States Bureau of Reclamation

USFS	United States Forest Service
USGS	United States Geological Survey
WCDG	*Water Crossing Design Guidelines*
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WSEL	water surface elevation

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1–23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 166 crossing of Olney Creek at milepost (MP) 4.52. This existing structure on SR 166, which has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 15.0201 0.90), has an estimate 8,255 linear feet (LF) of habitat gain.

Per the injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing as defined in the injunction. Avoidance of the stream crossing was determined not to be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a structure designed using the unconfined bridge methodology.

The crossing is located in WRIA 15 with the upstream (US) portion of the crossing located in Kitsap County and the downstream (DS) portion located in the city of Port Orchard. The highway travels in an east–west direction at this location and is approximately 1 mile upstream of Sinclair Inlet. Olney Creek generally flows from south to north beginning approximately 1.8 miles upstream of the SR 166 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 4-foot-wide by 4-foot-tall by 170-foot-long, four-sided concrete box culvert with a structure designed to accommodate a minimum hydraulic opening of 32 feet (ft). The proposed structure is designed to meet the requirements of the federal injunction using the unconfined bridge design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2019).

No structural recommendation is made at this time. Structure type is not being recommended by Headquarters Hydraulics and will be determined by others at future design phases.

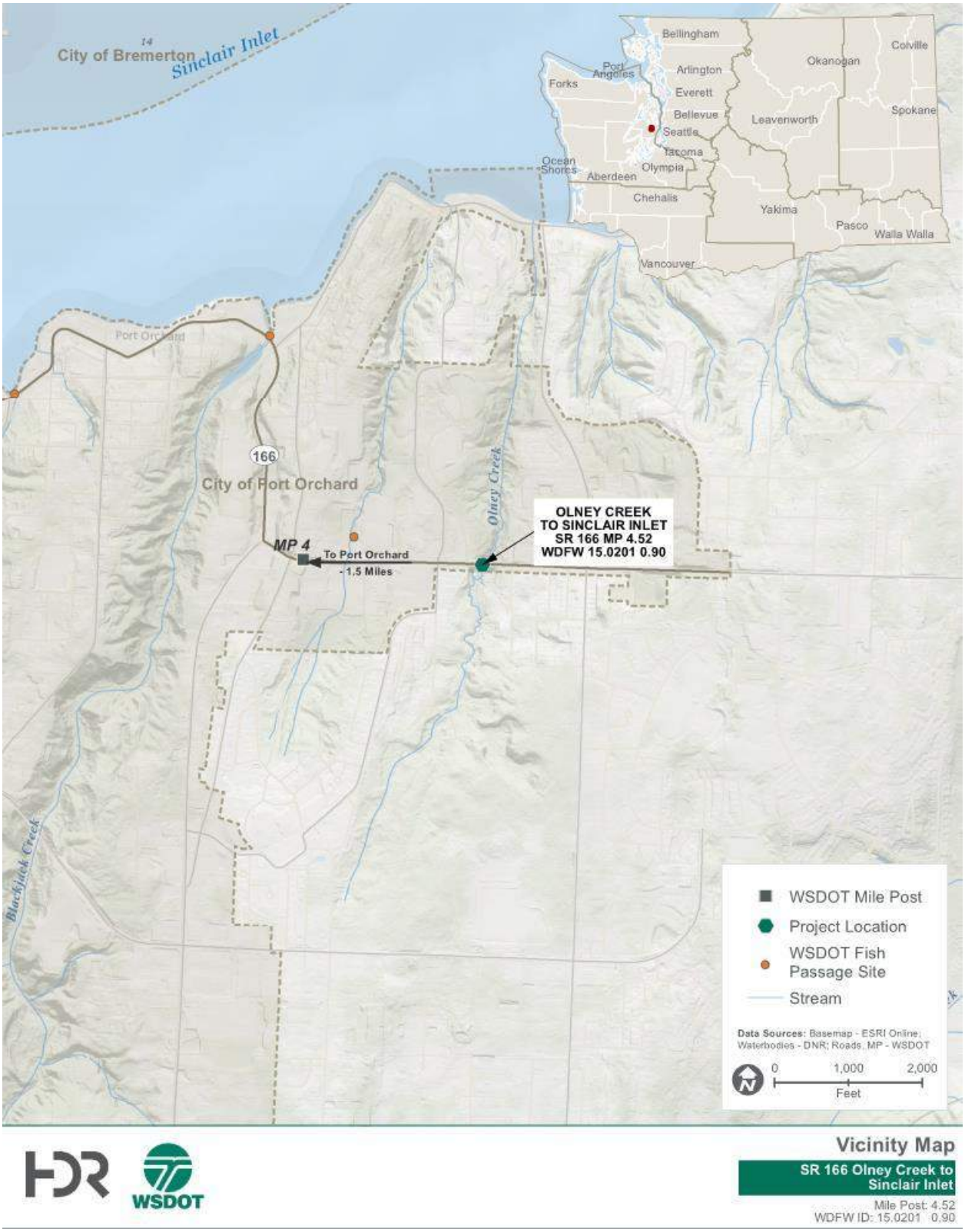


Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This assessment was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observation, maintenance, and fish passage evaluation.

2.1 Watershed and Land Cover

The project watershed, located south of the MP 4.52 project site, encompasses an area of 1.38 square miles. The crossing is located approximately 5,000 feet upstream of the outlet to Sinclair Inlet and has no major tributaries. The basin is relatively flat, with steeper grades occurring only near the channel or from cut and fill associated with development.

Current land cover was classified using National Land Cover Database (NLCD) classifications. Currently, this basin is dominated by low- to medium-density and open-space development. The 2016 NLCD map (Figure 2) shows land cover to be approximately two-thirds developed. Undeveloped areas are primarily forested. The distribution is shown in Table 1.

Table 1: Land cover

Land cover class	Basin coverage (percent)
Barren Land	0.1
Deciduous Forest	5.9
Developed, High Intensity	1.3
Developed, Low Intensity	40.0
Developed, Medium Intensity	14.6
Developed, Open Space	11.3
Evergreen Forest	20.9
Hay/Pasture	0.6
Mixed Forest	4.6
Open Water	0.3
Shrub/Scrub	0.4

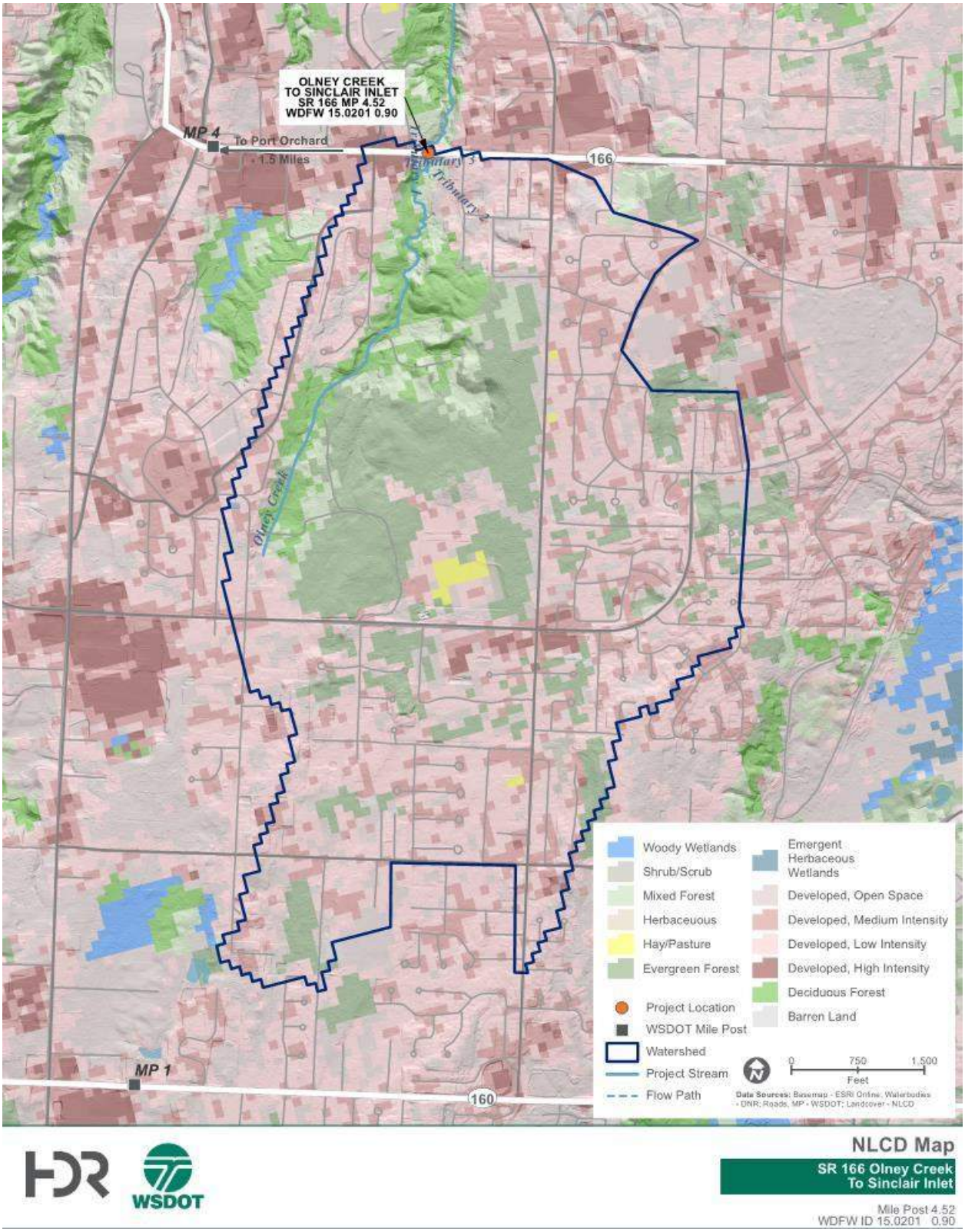


Figure 2: Land cover map (NLCD 2016)

2.2 Geology and Soils

Geologic information for the basin was mapped at a 1:100,000 scale (WDGER 2016) and obtained from the Washington State Department of Natural Resources (DNR) Geologic Information Portal. The geology of the watershed for this project site is composed of the geologic units described below and referenced in Figure 3. The basin is primarily Vashon advance outwash (Qga) which includes pebble to cobble gravel, sand and layers and lenses of silt and clay that was deposited during Vashon glacial advance. It is likely this geology would provide a steady source of material to Olney Creek. No landslide hazards were identified in the DNR Geologic Information Portal within the project basin.

- **Qga:** Pleistocene Age, advance continental glacial outwash, Fraser-age, mostly Vashon Stade
- **Qgt:** Pleistocene Age, continental glacial till, Fraser-age, mostly Vashon Stade
- **Qa:** Quaternary Age, alluvium
- **Qgu:** Pleistocene Age, glacial drift (undivided)

Soils in the channel vicinity are composed primarily of two units according to the Natural Resources Conservation Service (NRCS) Web Soil Survey (2021) (Figure 4). The Indianola-Kitsap complex is a loamy sand with a glacial outwash parent material and the Kitsap silt loam has a parent material of lacustrine deposits with volcanic ash in the upper part. These appear to be consistent with the streambed materials found during the field visit, discussed in Section 2.8.3.

Test borings were taken at the site by WSDOT drill crews as part of a geotechnical investigation (WSDOT 2021). No bedrock was encountered in the two borings. The borings were used along with DNR mapping to define five Engineering Stratigraphic Units (ESUs) at the site. A shallow foundation supported by ESU 3 is anticipated to be adequate for the crossing but it may need to be characterized further to verify anticipated conditions. Seismic conditions also need to be assessed for the structure due to the anticipated structure width and fill height.

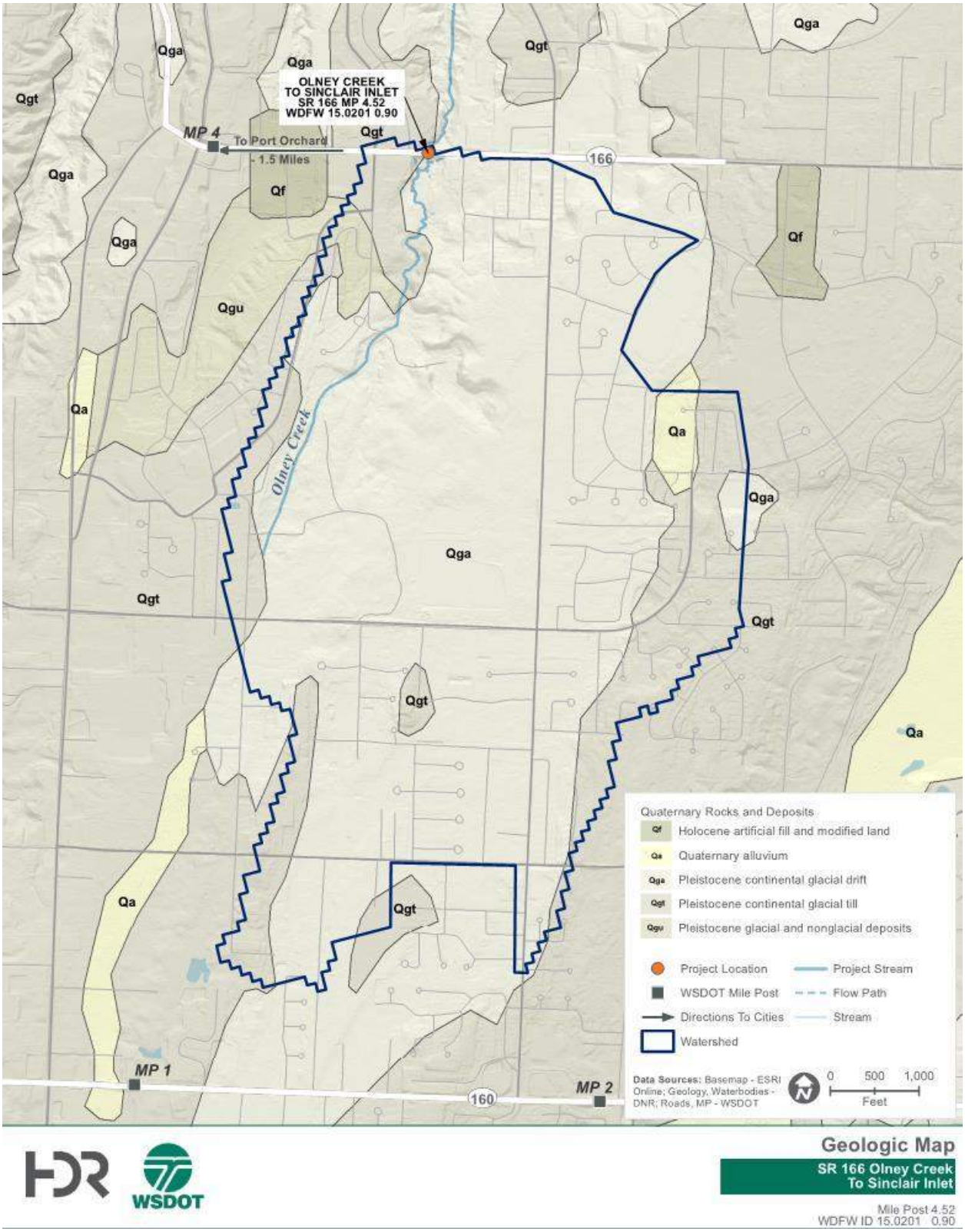


Figure 3: Geologic map

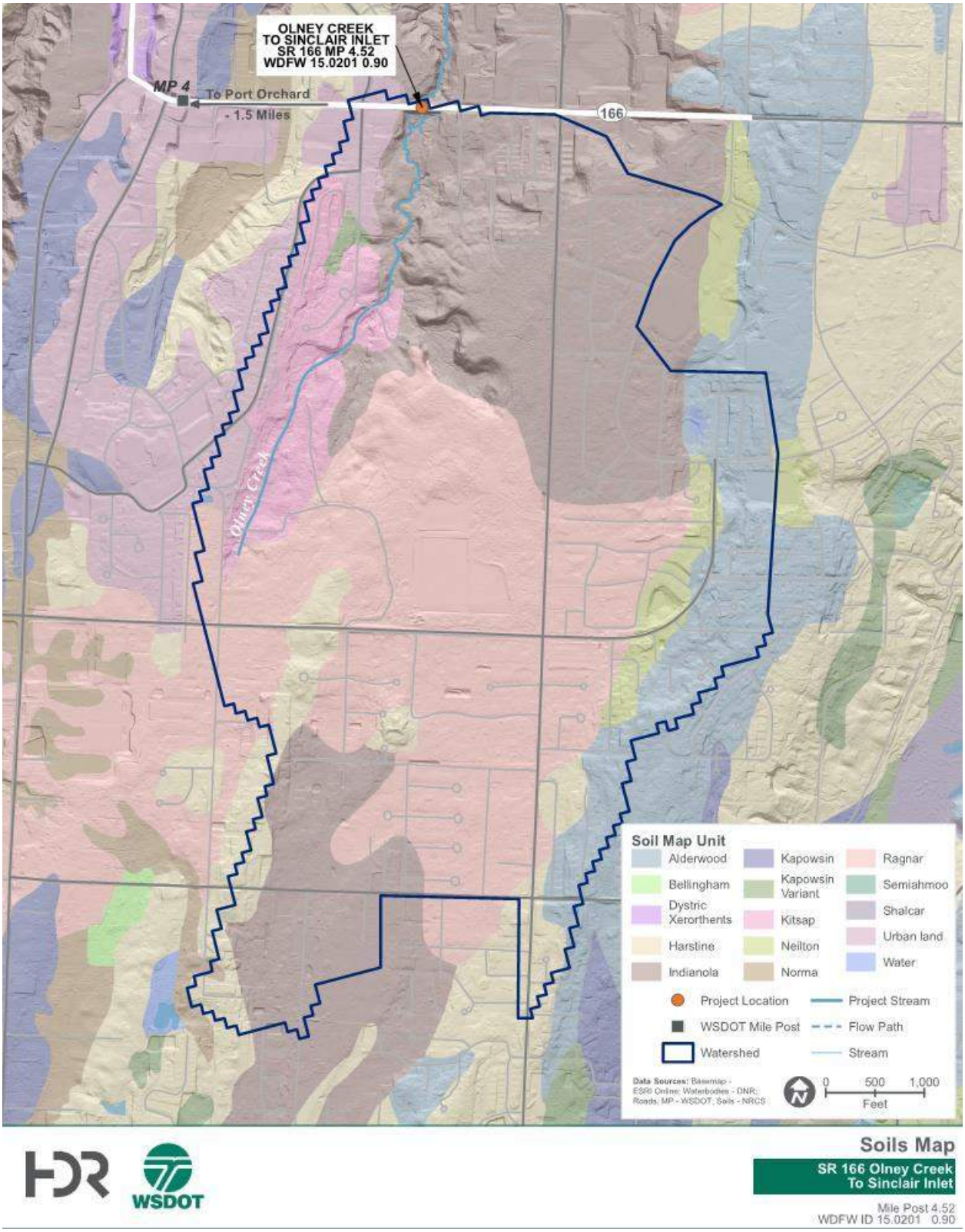


Figure 4: Soils map

2.3 Floodplains

The project area is located within a Zone A special flood hazard area (SFHA) based on the FEMA Flood Insurance Rate Map (FIRM) 53035C0390F, effective date February 3, 2017 (FEMA 2017). See Appendix A for the FIRMette containing flood zone information at the project site. The Zone A designation means that the project site is subject to inundation on a 1 percent annual chance flood event, though a detailed hydraulic analysis has not been conducted and base flood elevations or flood depths have not been determined.

No maintenance records were provided for this crossing, so there is no additional information regarding historical flooding, anecdotal descriptions of flooding, or high water marks.

2.4 Site Description

According to WDFW, the crossing is currently a barrier because of slope, which was listed as 3 percent, with 0 percent passability (WDFW 2011). Fish habitat is negatively affected because it is difficult for fish to migrate upstream through the culvert slope. The steep, undersized culvert results in excessive velocities and/or insufficient water depth for fish passage. The total length of potential habitat gain is 8,255 LF. This crossing is not classified as having a chronic environmental deficiency and no maintenance records were provided.

2.5 Fish Presence in the Project Area

Olney Creek is a small, coastal stream that flows to Sinclair Inlet, off south Puget Sound. The stream is documented to support Coho Salmon (*Oncorhynchus kisutch*), Chum Salmon (*Oncorhynchus keta*) as well as resident Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*) (SWIFD 2018; WDFW 2021a, 2021b; StreamNet 2021). Coho fry and trout were observed during the WDFW habitat survey of the stream in 2008 (WDFW 2008). Under current conditions, according to WDFW (2011), the creek in the project reach is inaccessible to anadromous salmonids coming up from Sinclair Inlet because of the presence of piping and culvert barriers at the mouth of the creek by Beach Drive (Sites 995350 and 920413) and a private culvert (site 999570). If these downstream barriers were removed, then Coho Salmon and steelhead could make use of habitat upstream and downstream of the project reach. However, it should be noted that according to WDFW (2006), coho salmon and cutthroat trout have been observed upstream of the project reach. The small size and limited suitable large spawning gravel habitat in Olney Creek likely precludes spawning of the largest salmon species such as Chinook Salmon in this stream. Chinook Salmon that inhabit Sinclair Inlet are part of the Puget Sound Evolutionary Significant Unit and are listed as threatened under the Endangered Species Act (ESA) (NMFS 2005). Steelhead that inhabit Sinclair Inlet are part of the Puget Sound distinct population segment (DPS) and are also listed as threatened under the ESA (NMFS 2007).

Olney Creek in the project reach does not provide suitable Chinook spawning habitat but spawning is documented in nearby Blackjack Creek (SWIFD 2018, WDFW 2021a). Juvenile fall Chinook salmon migrate out to the ocean in their first spring after hatching and emerging from the gravel. Juveniles dispersing along the shoreline of Sinclair Inlet could potentially move up into the lower reaches of Olney Creek during their spring rearing and outmigration. The project crossing is approximately 4,600 feet upstream of Sinclair Inlet and juvenile Chinook would not

disperse upstream as far as the project crossing. Therefore, Chinook salmon are not expected to occur in the project reach.

Steelhead are present throughout many western Washington streams and rivers and are documented in nearby Blackjack Creek (SWIFD 2018, WDFW 2021a). They generally prefer fast water in small to large mainstem rivers and medium to large tributaries. Steelhead life history is highly variable and juveniles typically spend 1 to 3 years rearing in fresh water (Wydoski and Whitney 2003). Juveniles disperse into tributaries and off-channel habitat during high winter flows and could use Olney Creek for this purpose.

Coho Salmon use small streams, are widespread in small rivers throughout western Washington, and can be found in many small coastal streams with year-round flow. Coho Salmon presence is documented in Olney Creek downstream of the project crossing (SWIFD 2018, WDFW 2021a). Once barriers are removed, coho could make use of spawning and rearing habitat in Olney Creek upstream of the SR 166 crossing. Juveniles overwinter for at least 1 year throughout rivers and tributaries prior to migrating out to the ocean and rearing habitat is present throughout the surveyed reaches.

Chum Salmon also are widespread in coastal streams with low gradients and velocities and the lower reaches of larger rivers, and often use the same streams as Coho, but Chum generally spawn closer to saltwater. Chum Salmon fry do not rear in fresh water for more than a few days. Shortly after they emerge, chum fry move downstream to the estuary and rear there for several months before heading out to the open ocean. Chum Salmon are documented to occur in the lower reaches of Olney Creek near its confluence with Sinclair Inlet (WDFW 2021a; SWIFD 2018) and could move into the project reach once barriers are removed.

Coastal Cutthroat Trout are also widespread throughout small streams in western Washington and are documented to occur in Olney Creek (SWIFD 2018, WDFW 2021b). They seek smaller streams with minimal flow and small gravel substrate including sand. They prefer the uppermost portions of these streams, areas that are generally too shallow for other salmonids. They can be anadromous and rear in streams for 2 to 3 years or be resident and remain entirely in fresh water (Wydoski and Whitney 2003). Because the project culvert is impassable, as well as several other barriers in the creek, cutthroat that inhabit Goodnough Creek are resident, but with downstream barrier removal a sea-run population could be supported.

Bull trout (*Salvelinus confluentus*) have more specific habitat requirements than most other salmonids; in particular they require cold water (46 degrees Fahrenheit [°F] or below) for spawning and egg incubation, and abundant instream cover for rearing (Rieman and McIntyre 1993). They typically spawn and rear in the cold, clear tributaries in the upper portions of watersheds. Bull trout are typically found in snowmelt-dominated streams that maintain cold water temperatures in headwater tributaries year round. The rainfall-dominated streams in the low-elevation areas around Sinclair Inlet do not provide this type of habitat. Olney Creek has seasonal low flows and lacks the cool flowing, clear stream characteristics for bull trout habitat. Bull trout are not documented to occur and are not expected to be present in Olney Creek and the project reach.

Table 2 provides a list of salmonid fish species that would potentially occur in Olney Creek once passage barriers are removed.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho Salmon (*Oncorhynchus kisutch*)	Documented downstream	SWIFD 2018, StreamNet 2021, WDFW 2021a, WDFW 2021b	Not warranted
Chum Salmon (*Oncorhynchus keta*)	Documented downstream	SWIFD 2018, StreamNet 2021, WDFW 2021a, WDFW 2021b	Not warranted
Puget Sound Steelhead (*Oncorhynchus mykiss*)	Potential Presence Documented in Sinclair Inlet	SWIFD 2018, WDFW 2021a, WDFW 2021b	Threatened
Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*)	Documented	SWIFD 2018, WDFW 2021b	Not warranted

2.6 Wildlife Connectivity

The 1-mile-long roadway segment that Olney Creek crosses is ranked low for wildlife-related safety. WSDOT has determined that in order to be eligible for a habitat connectivity analysis, fish barrier correction projects must cross under or adjacent to a high-priority road segment, or a project team member can request the analysis.

2.7 Site Assessment

The following sections describe the existing conditions of Olney Creek as observed during the site visits.

2.7.1 Data Collection

HDR Engineering, Inc. (HDR) conducted an independent site visit on April 5, 2021, to measure bankfull width (BFW), collect pebble count data, locate a reference reach, document stream conditions, and assess fish habitat character and quality within the project reach. A second site visit with HDR, WSDOT, WDFW, and the tribes for BFW concurrence has not yet been conducted.

WSDOT provided survey data in March 2021. The survey extends 335 feet upstream of the culvert, 350 feet downstream of the culvert, and a total roadway length of 1,500 feet. Survey information generally includes stream channels and overbank areas along the channel.

2.7.2 Existing Conditions

The existing structure is a 4-foot-high by 4-foot-wide, four-sided concrete box culvert. The culvert inlet has 20-degree wingwalls, a short headwall, and a bottom apron that extends out as

far as the wingwalls (Figure 5). The culvert outlet has similar characteristics to the inlet except a 20-degree skew toward the right bank and 35-degree wingwalls. The culvert gradient is 2.4 percent and it is perpendicular to SR 166 under approximately 40 feet of fill. The concrete appears to be in good condition. As-built drawings were not obtained for the site. This section summarizes the field report; the full report can be found in Appendix B. Results, locations and photos of the BFW measurements are provided in Section 2.8.2.

Figure 5: Culvert inlet

The upstream reach is characterized by a riffle pool morphology, meandering planform, abundant large woody material (LWM), and a bed comprising gravel and sand. At the start of the upstream topographic survey limits the flow is immediately directed to the right bank by a channel-spanning log jam (see Figure 6). The flow then widens out to a relatively straight, shallow section with gravel bars along each bank. This is where the first BFW measurement (BFW 1) was taken, as shown in Figure 17. LWM along the left bank then constricts the channel again, which then flows under a channel-spanning log.

Figure 6: Upstream survey extents looking downstream

Downstream of the log, the channel returns to a wide, flat section with a slight left bend. A natural log step creates a small water surface drop and a steep left bank and the cedar stump forces the flow right. The main channel then takes a 180-degree bend to the right, thus forming a gravel point bar on the inside of the bend. A small tributary (Tributary 1) enters the left bank (Figure 7) of the main channel in the middle of the bend. The tributary substrate is a sandy, gravelly mix slightly smaller than that observed in the main channel. Several stormwater outfalls drain to this tributary. In the same vicinity of the tributary, groundwater seeps were observed and identified by orange soils and hydric vegetation (skunk cabbage).

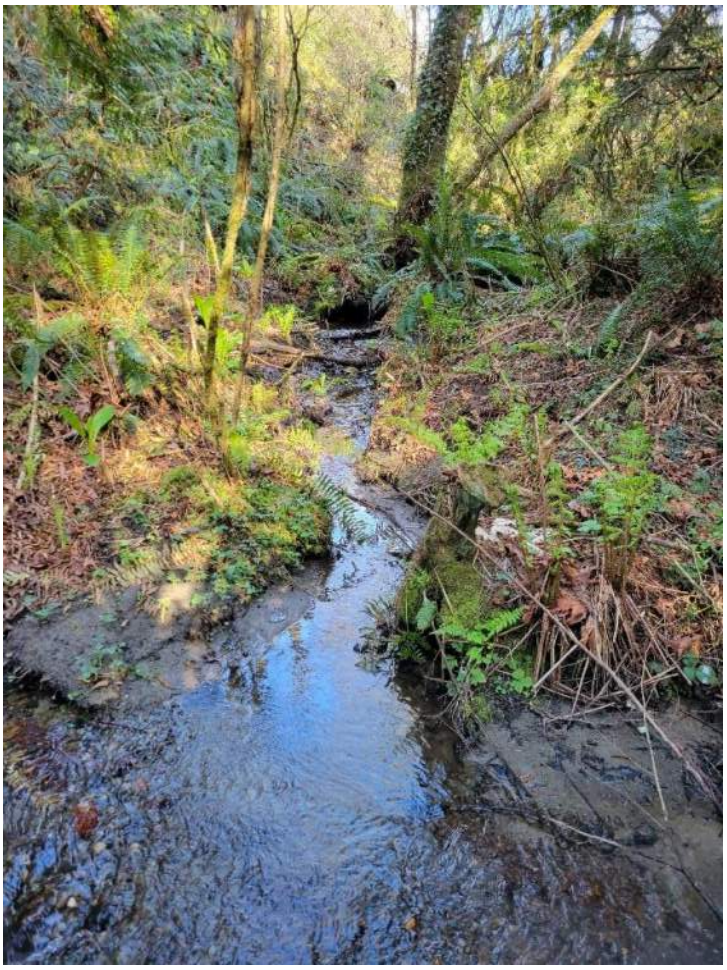


Figure 7: Tributary 1 enters Olney Creek at bottom of photo

Coming out of the 180-degree bend, the thalweg migrates toward the right bank of the channel. The right bank in this straight section has a 2- to 3-foot right bank. As the main channel straightens out there is another channel-spanning log several feet above the water surface. This is where BFW 2 was taken and the upstream reference reach was identified (Figure 18). As the channel meanders to the right, gravel bars form on the left side of the channel, resulting in an asymmetrical channel shape. The channel has access to a wide, flat floodplain along the left bank, which is characterized by saturated soils and hydric vegetation until it meets the road embankment at the culvert inlet.

Downstream of the reference reach, the channel turns 90 degrees north before straightening out again. LWM on the left bank directs the channel against the right bank and then opens up to a straight section containing a mid-channel bar, shown in Figure 8. A small tributary (Tributary 2) enters the channel along the right bank at the mid-channel bar. This tributary has no known stormwater inputs but has similar features along it as found in Tributary 1 including groundwater seeps, saturated soils, and hydric vegetation. Downstream of the mid-channel bar, the channel narrows and flows under a log bridge formed between two stumps (Figure 9). There is a gravel bar on the left side of the channel under the log bridge.

Figure 8: Mid-channel bar looking downstream

Figure 9: Log bridge looking upstream

Immediately upstream of the inlet the water surface drops approximate 1 foot because of accumulated woody material and large rocks. There was significant erosion along the left side of the inlet and behind the left wingwall (Figure 5 above).

Downstream Reach

The downstream end of the culvert is the same size and material as at the inlet end. The headwall and wingwalls are skewed slightly to the right to direct flows in a more downstream direction. Large angular rock and accumulated woody material at the outlet create backwater within the culvert, so that the culvert was half full of streambed material (Figure 10).

Figure 10: Culvert outlet

Immediately downstream of the culvert, the channel travels through a large pool formed by large angular rock and LWM, and then cascades down to a 90-degree bend. The bend to the right approximately 15 feet downstream of the culvert outlet has a moderate amount of bank erosion from the bend near the culvert outlet. The channel then flows parallel to SR 166 for approximately 100 feet. This section is highly confined by the road fill slope on the right bank and steep left bank for the first 50 feet downstream of the culvert inlet. This section contains large downed trees and recently cleared vegetation and far less understory vegetation overall than in the upstream section (Figure 11). There was also some angular rock mixed in with the rounded rock in this section, likely recruited from the road embankment.

Figure 11: Straightened channel section looking upstream

The channel then bends to the left and some potential floodplain access opens on the left. The right bank is steep through this bend and there was minor bank undercutting. As the channel straightens out two approximately 3-foot-diameter logs are spaced 10 feet apart across the channel. The water surface was at or within approximately 6 inches (in) of the bottom of the logs and the channel width was narrowed through the section. At high flow events these two logs likely create backwater as flow is forced under them (Figure 12).

Figure 12: LWM bridges looking downstream

Downstream of the logs the channel returns to its more typical section seen upstream of the crossing with abundant LWM complexity, and has floodplain access above both banks. The channel width is initially constricted by an LWM piece along the right bank, and then it widens downstream. Fine-grained sediment is deposited behind an LWM piece positioned parallel along the right bank. This is where BFW 3 was taken (Figure 19).

Downstream of the BFW 3 measurement, a long parallel piece of LWM along the right bank diverts flow to the left side of the channel. There is fine sediment deposited behind the log and a point bar on the inside of the bend. There is also a marked increase in understory vegetation in this section. Farther downstream, within about 25 feet a large log on the left bank diverts flow back to the right. Within this section there are multiple pieces of LWM spanning and running lengthwise along the channel, resulting in small water surface drops and forming deep pools (Figure 13).

Figure 13: LWM creating small drops and pools

The channel then straightens out for a short section and increases in slope, which carries through and beyond the downstream topographic and reconnaissance survey extents. BFW 4 was taken just upstream of the topographic survey limits (Figure 20). This was also the location of the downstream reference reach and where the second pebble count took place. The largest natural particle size observed in the downstream reach was 5 inches.

As a whole, the planform of the downstream channel can be characterized as a single-threaded channel with a riffle-pool morphology and abundant LWM. No obvious signs of maintenance activity were observed at the crossing. There are several stormwater outfalls from surrounding development in the immediate vicinity of the crossing as well as other utilities along SR 166 including but not limited to sanitary sewer, communications, and overhead power.

2.7.3 Fish Habitat Character and Quality

Upstream of the SR 166 crossing, Olney Creek flows through a mixed forest corridor bounded by roads and development. The mature tree cover consists of western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), and western red cedars (*Thuja plicata*). The shrub understory is dominated with native species including salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), osoberry (*Oemleria cerasiformis*), and several species of ferns. The mature forest and shrub

cover provides good shading, nutrient inputs, and potential for LWM recruitment. LWM is important in western Washington streams in that it provides cover for fish and contributes to stream complexity, which is beneficial to salmonids.

LWM was present within the stream channel and banks throughout the upstream reach. There were 12 pieces of LWM in and across the channel within the surveyed reach, including three places where logs in the streambed formed short water surface drops (Figure 14). The LWM ranged from approximately 8 to 18 inches in diameter and a large cedar stump was present on the right bank near the downstream end of the reach that created a scour pool (Figure 9 above). The presence of LWM throughout the stream channel provides habitat complexity and cover for salmonids using this reach for rearing and migration during high flow periods. These functions are limited during summer low flows where shallow water and LWM debris jams can impede fish movement through this reach. Returning Coho Salmon often gather at the mouths of streams and wait for the water flow to rise, such as after a rainstorm, before heading upstream. The higher flows and deeper water enable the fish to pass obstacles, such as logs across the stream or beaver dams that would otherwise be impassable. The abundant LWM provides good cover and habitat complexity for rearing salmonids throughout the upstream reach.

Figure 14: Logs in the streambed formed short water surface drops in the upstream reach

Pools, and the transition areas between pools and riffles, are important habitat for adult and juvenile salmon. The slow water of pools allows the fish to rest, and the depth provides protection from predators, as well as cooler water. The stream is small and shallow, and instream habitat consists predominantly of shallow riffles and glides with small pools associated with LWM. Eleven small pools were located throughout the upstream reach that ranged from about 2 feet to 8 feet long, with depths at the time of the field visit up to approximately 2.5 feet.

These pools provide habitat function with cover and flow refuge areas particularly for rearing juvenile salmonids. The combination of LWM, meanders, and scour create habitat complexity in pool to riffle areas as well as gravel bars on the inside of bends. These features provide good rearing habitat for juvenile salmonids by providing areas of cover and refuge, as well as accessible riffle areas that are important for providing invertebrate food sources.

The upstream reach of Olney Creek provides both spawning and rearing habitat for salmonids (WDFW 2008). The stream substrate consists of fines and small gravel making the upstream reach not suited for spawning of the largest salmon species that include Chinook Salmon. The small gravel sizes in the project reach are not well suited for steelhead spawning, but they often overlap with Coho Salmon and could also potentially spawn in Olney Creek. Smaller species that use smaller gravel and spawn in small western Washington tributaries including Coho Salmon, Chum Salmon, and Cutthroat Trout could make use of the project reach for spawning and rearing.

The downstream reach flows along the base of the SR 166 road embankment for the upper part of the reach before it bends into a wider forested area. The riparian corridor consists of mature mixed forest trees on steep embankments on both sides including alders, hemlock, bigleaf maple, Douglas fir, and western red cedar. The shrub understory is predominantly native shrub vegetation including salmonberry, vine maple, osoberry, and several species of ferns. Invasive English ivy (*Hedera helix*) was present climbing several large trees near the downstream end of the reach along the left bank. Himalayan blackberry was present on the road embankment and holly (*Ilex aquifolium*) was also present in a few places on the right bank.

The riparian corridor is confined by the roadway near the right bank and surrounding residential development. The mature forest cover does provide shading of the stream, nutrient inputs, as well as some LWM recruitment. LWM was abundant in the downstream reach providing habitat complexity and cover for rearing and migrating salmonids. Several trees from the steep left bank hillslope had fallen across the channel with branches that extend into the wetted channel (Figure 11 above). There were 22 pieces of LWM in the downstream reach that included large trees laying across the bankfull channel as well as logs in the bed and bank that provided pool formation.

The stream is small and shallow, and instream habitat consists predominantly of shallow riffles and glides with a series of small pools associated with LWM and scour. There were five small pools in the surveyed downstream reach that ranged in size from 3 to 8 feet, and up to 1.5 feet deep. Substrate in the downstream reach consisted of gravel, small cobbles, and fines mostly associated with the small pools. Some small areas of spawning habitat were present in gravel patches and pool tailouts throughout the reach. Although limited, some potential spawning habitat for Coho Salmon and Cutthroat Trout is present. The LWM and pool-riffle areas provide good rearing and migratory habitat for juvenile salmonids to disperse, overwinter, and rear.

2.8 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the basic geometry and cross sections of the channel, stability of the channel both vertically and laterally, and various habitat features.

2.8.1 Reference Reach Selection

Both an upstream and downstream reference reach were identified at the initial field visit because of the very different channel configurations observed on each side of the crossing. In general, the upstream channel is less confined and shallower in slope, while the downstream section is confined with generally steeper slopes. With the exception of the middle portion of the upstream reach, the channel throughout the surveyed reach is confined. The differences are discussed further in Section 2.8.2.

A section of stream approximately 175 feet upstream of the culvert (Figure 15) was chosen as the reference reach because it appears to be most representative of a naturally occurring streambed with the least amount of anthropogenic influences. This reach has an average channel gradient of 1.5 percent. Further upstream within the survey limits and immediately upstream of the culvert the channel is confined. A pebble count was conducted within the reference reach; results are summarized in Section 2.8.3. Figure 16 shows the locations of the reference reach, BFW measurements, and pebble counts. This reference reach was used for proposed design channel shape and to compare the existing channel to proposed hydraulic results throughout this Preliminary Hydraulic Design (PHD) Report. The downstream reference reach, shown in Figure 20, had a narrower BFW measurement, confined FUR, and steeper channel slope of 2.4 percent, which agrees with the prevailing longitudinal slope discussed in Section 2.8.4.

Figure 15: Photo of upstream reference reach, looking downstream

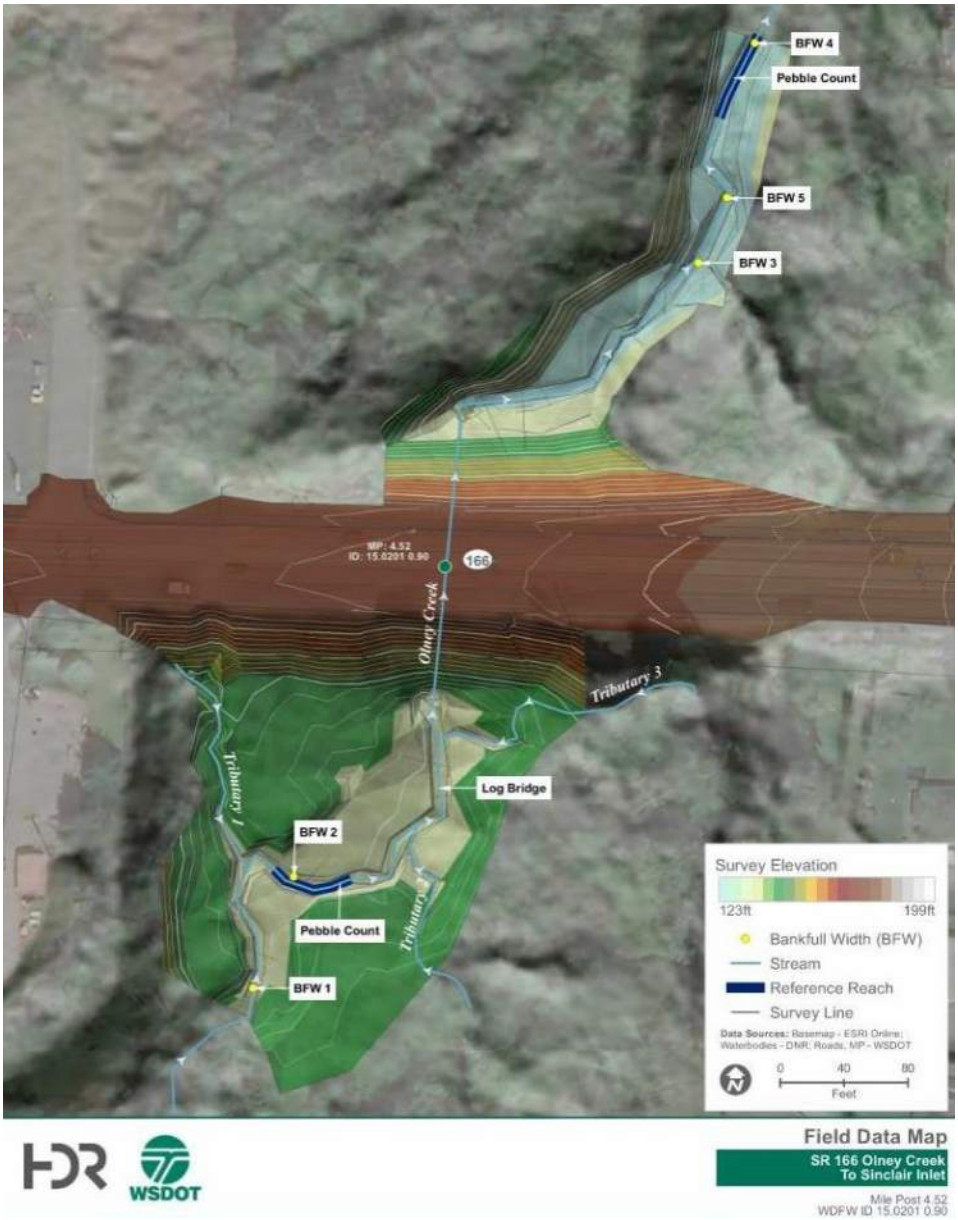


Figure 16: Reference reach, bankfull width, and pebble count locations

2.8.2 Channel Geometry

During the site visit performed on April 5, 2021, four BFWs were measured in the field, two upstream of the crossing and two downstream. The BFWs ranged from 11.3 to 14.5 feet. Figure 17, Figure 18, Figure 19, and Figure 20 show the stream conditions where all BFWs were measured, and Figure 16 shows the overall location where these BFWs were measured. A BFW concurrence meeting with HDR, WSDOT, WDFW, and the tribes was conducted on September 22, 2021. An additional bankfull width measurement was taken downstream of the crossing and a previously taken measurement was revised. Table 3 summarizes BFW measurements collected and whether they were included in the design average. The design average BFW is 13.2 feet.

Figure 21 shows typical cross sections, taken from survey, at the project site: one upstream of the crossing within the reference reach, one just upstream of the culvert, and one downstream of the

culvert. Channel shape is relatively similar through both the upstream and downstream reaches though the banks in the upstream reach are lower, allowing for floodplain access at lower flows.

The width-to-depth ratio, measured at the reference reach cross section at existing Station (STA) 57+96, is approximately 11:1. The channel evolution stage was evaluated in the reference reaches and estimated to be in Stage I of the Channel Evolution Model (Schumm et al. 1984).

Figure 17: BFW 1 measurement location facing upstream

Figure 18: BFW 2 measurement location facing upstream

Figure 19: BFW 3 measurement location facing downstream

Figure 20: BFW 4 measurement location facing downstream

Table 3: Bankfull width measurements

	BFW #	Width (ft)	Included in design average
US	1	13.0	Yes
	2	14.5	Yes
DS	3	13.5	Yes
	4	11.3	Yes
	5	13.5	Yes
	Design average	13.2	

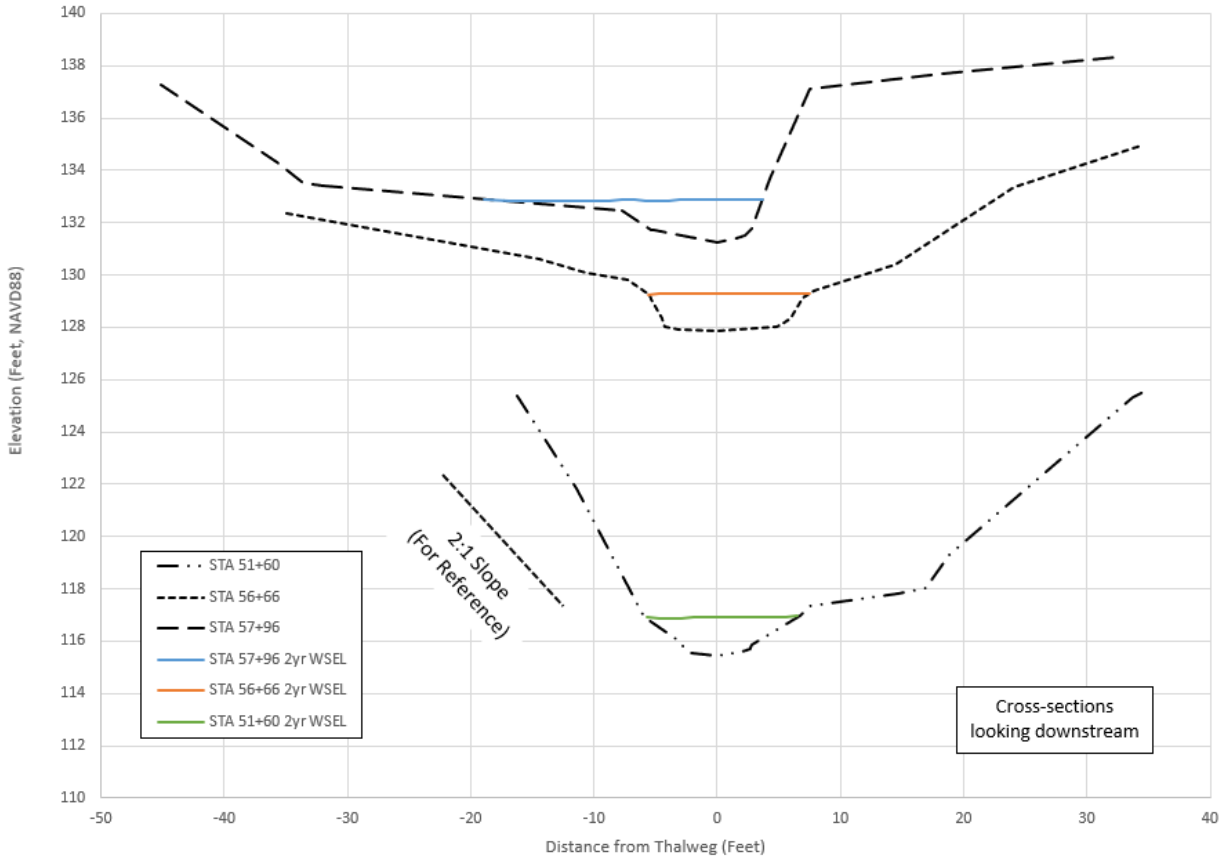


Figure 21: Existing cross-section examples (note: 2 feet added to STA 57+96 XS elevations to show more clearly)

2.8.3 Sediment

Two pebble counts, each of about 150 particles, were performed within the reference reaches, one upstream and one downstream of the crossing (Figure 16). Two pebble counts were considered adequate since the material throughout the reach was consistent visually and clearly smaller than the streambed substrate specification material to be proposed. The cumulative distribution and specific pebble sediment sizes are provided in Figure 22 and Table 4. Material consists primarily of fine to coarse gravels. Only one small cobble was observed in the downstream reference reach, but several were observed outside the reference reach including the largest material observed, which was approximately 5 inches in diameter. Figure 23 shows a photo of the typical material found throughout the upstream reach and Figure 24 shows the largest observed material throughout the project reach.

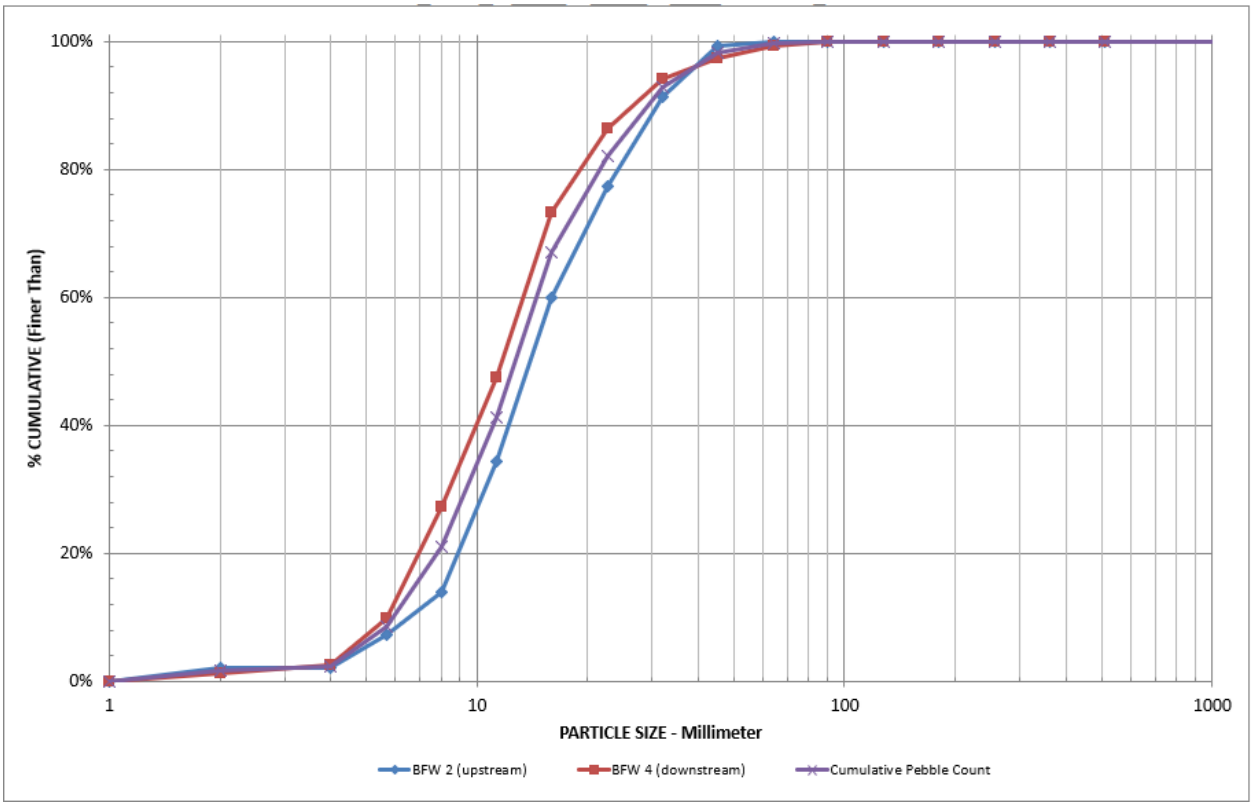


Figure 22: Sediment size distribution in the reference reach

Table 4: Sediment properties

Particle size	Upstream diameter (in)	Upstream diameter (mm)	Downstream diameter (in)	Downstream diameter (in)	Cumulative diameter (in)	Cumulative diameter (mm)
D_{16}	0.3	8.2	0.2	6.3	0.3	6.8
D_{50}	0.6	14	0.5	11.7	0.5	12.7
D_{84}	1.0	26.3	0.8	21.2	0.9	24
D_{95}	1.5	37.5	1.4	35	1.4	36.7
D_{100}	2.5	63.5	3.5	88.9	3.0	76

Figure 23: Typical channel substrate material within reference reach

Figure 24: Largest observed particle within project reach

2.8.4 Vertical Channel Stability

A long profile was developed from 2021 WSDOT topographic survey data and 2018 Olympic Peninsula and Southwest Counties (OPSW) Kitsap County light detecting and ranging (LiDAR) data set (USGS and Quantum Spatial 2018). The LiDAR data used in the analysis were obtained from the DNR LiDAR Portal and were in a bare earth raster format with 3-foot cell resolution. The channel profile shown in Figure 25 describes slopes approximately 6,000 feet upstream and 6,000 feet downstream from the project site based on LiDAR data and includes major landmarks along the creek. Immediately upstream of the project site, the average slope of the channel is 1.8 percent for about 600 feet and upstream of that it is 2.4 percent for approximately 2,000 feet. Located at an approximate distance of 2,600 feet from the upstream end of the project site is a dam and an obsolete gravity diversion line with an average slope of 7.2 percent from downstream to upstream of the dam. This dam acts as a grade control feature, thus separating the creek into two distinct sections from a hydraulic standpoint. On the downstream side of the project site the average slope is 2.4 percent for about 500 feet, then it increases to 3.3 percent for approximately 500 feet downstream of that. The average slope decreases to 2.3 percent at approximately 1,000 feet downstream of the project site and continues downstream for about 2,000 feet.

HDR made observations on sediment supply and overall geomorphological conditions of the site during site visits. Point bars and mid-channel bars were present upstream of the project site. The channel does not seem to show signs of vertical incision and the channel bed material consists of gravel and sand. Based on the site observations, the channel seems to have a healthy sediment supply. Photos of the upstream dam at STA 83+30 (accessed through WDFW Fish Passage Inventory Web Application [WDFW 2011]), along with the average slopes shown in Figure 25, indicate sediment deposition up to the crest of the dam at its upstream side.

The overall average slope of the channel is 2.4 percent based on the data presented in Figure 25. Based on average reach slopes described above, the location of the project site on the long profile of Olney Creek seems to be perched when considering the prevailing channel slopes upstream and downstream of the crossing. This finding may indicate a potential for future long-term degradation at the project site. See Section 8.2 for discussion of long-term degradation potential. As the design progress, analysis of long-term degradation should be revisited.

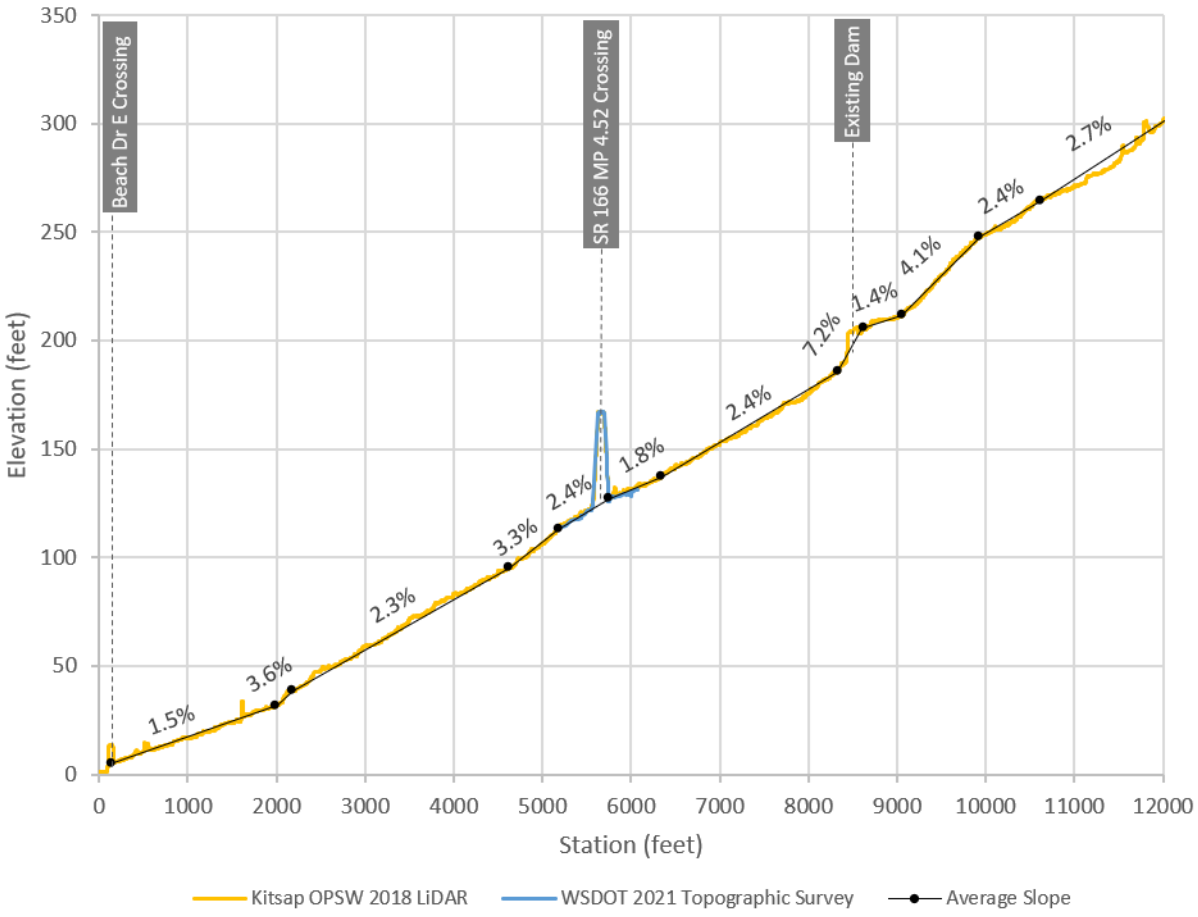


Figure 25: Watershed-scale longitudinal profile

2.8.5 Channel Migration

Channel migration was assessed using historical imagery, modeling results, and field observations. The historical aerial imagery gives little information on channel migration near the project site because the channel is in a forested area, making it difficult to determine where the channel is located in each aerial photo. The risk of channel migration in the downstream reach is low, as it is confined by very high nearby valley walls and development. The risk of channel migration in the upstream reach is also low, though with the gentler slope and unconfined planform, it may migrate within the valley walls. This is not anticipated to affect the crossing.

2.8.6 Riparian Conditions, Large Wood, and Other Habitat Features

The mixed mature forest cover in the riparian corridor of the upstream reach is bounded by roads and development, restricting the corridor to approximately 450 feet in the surveyed reach. The forested area becomes wider to the south (upstream) where it is part of South Kitsap Regional Park (Figure 2 above). The forest is a mix of deciduous and conifer trees, predominantly red alder, western red cedar, hemlock, and Douglas fir. The shrub understory is dominated by native species including salmonberry, vine maple, osoberry, and several species of f

erns. Non-native Himalayan blackberry (*Rubus armeniacus*) is present in some of the open areas along the road embankments at the culvert inlet and outlet. Wetland areas in the floodplain with hydrophytic vegetation including skunk cabbage (*Lysichiton americanus*) are present at two locations in the upstream reach and associated with groundwater seeps.

LWM was present within the stream channel and banks throughout the upstream reach. There were 12 pieces of LWM in and across the channel within the surveyed reach, including three places where logs in the streambed formed small water surface drops (Figure 13 above). The LWM ranged from approximately 8 to 18 inches in diameter and a large cedar stump on the right bank along with a large fallen tree across the channel above bankfull including its rootwad was present near the downstream end of the reach that created a scour pool. The presence of LWM throughout the stream channel provides habitat complexity by promoting pool formation and providing cover for salmonids using this reach. The LWM and meanders in the stream channel form scour areas along the banks and result in gravel bars on the inside of bends.

Three small tributaries enter Olney Creek within the surveyed upstream reach (Figure 16 above). Tributary 1 enters the left bank of the main channel in the middle of a bend where a wetland and groundwater seeps were observed in the floodplain. A second wetland was also present along the left bank floodplain near the culvert inlet. Neither of these wetlands provide fish habitat but provide water retention and water quality function for the stream. A second small tributary (Tributary 2) enters the channel about 140 feet upstream of the culvert inlet. A third tributary (Tributary 3) enters the creek along the right bank approximately 30 feet upstream of the culvert inlet. This tributary is close to SR 166 and may convey some stormwater from the road prism.

In the downstream reach there is a plunge pool formed by riprap at the culvert outlet and subsequent small cascade. For the first 50 feet of the downstream reach the stream channel is confined by the road fill slope on the right bank and a steep forested left bank. The riparian corridor is confined by the roadway near the right bank and surrounding residential development. The riparian vegetation consists of mature mixed forest trees including alders, hemlock, bigleaf maple, Douglas fir, and western red cedar. The shrub understory is predominantly native shrub vegetation including salmonberry, vine maple, osoberry, and several species of ferns. Some non-native creeping buttercup (*Ranunculus repens*) was present on the left bank and invasive English ivy was present climbing several large trees near the downstream end of the reach along the left bank. Himalayan blackberry was present on the road embankment, and holly was also present in a few places on the right bank.

LWM was abundant in the downstream reach providing habitat complexity and cover for rearing and migrating salmonids. There were 22 pieces of LWM in the downstream reach that included large trees fallen across the bankfull channel as well as logs in the bed and bank that provided pool formation. The stream is small and shallow and consists predominantly of shallow riffles and glides with a series of five small pools associated with LWM and scour.

No beaver activity was observed in the upstream or downstream reach.

3 Hydrology and Peak Flow Estimates

USGS regression equations (Mastin et al. 2016) for Region 3 were used to estimate peak flows at Olney Creek (Table 5). Inputs to the regression equation included basin size and mean annual precipitation. Olney Creek to Sinclair Inlet has a basin area of 1.38 square miles with a mean annual precipitation of 51.4 inches (PRISM Climate Group 2019). The basin was delineated with StreamStats (USGS 2016) with small modifications interpreted from Kitsap County geographic information system (GIS)-mapped storm drains. The resulting basin is depicted in Figure 26.

Olney Creek is within a gaged basin (listed as OC Karcher Creek), but with only 7 years of flow data available from 1997 to 2003 (KPUD 2021). The gage was located on Olney Creek downstream of the crossing near Sinclair Inlet. The annual peak flows from this gage were input to HEC-SSP and a Bulletin 17B analysis was run to estimate flood-quantile flows. A Bulletin 17B analysis was run instead of a 17C analysis because the gage had fewer than 10 years of record making it incompatible with 17C methodology. Note, in general flood frequency analysis typically requires a minimum of 10 years of record to be valid. The flows were then scaled to the drainage area at the SR 166 crossing using the methods outlined by Mastin et al. (2016), specifically using equations 11 and 12. The scaled flood frequency results were compared to the regression results and agreed well and fell within the confidence intervals of the regression analysis. The scaled results were slightly higher for each peak flow event, so they were used for the hydraulic modeling.

The basin scaled 2-year peak flow was estimated to be 54 cubic feet per second (cfs), and the 100-year flow was estimated to be 134 cfs. Table 5 shows the calculated peak flows for Olney Creek. In addition to the existing-conditions hydrology estimates, WSDOT requires that anticipated future flows be accounted for by using the projected 2080 100-year event flows as a design check. For more information on how the 2080 predicted 100-year flow was determined, see Section 7.2.

Daily average flow values were also calculated for each month from the Olney Creek KPUD gage for the period of record. During the low flow summer months, average daily flow is approximately 3 cfs. January has the highest average daily flow of 8.4 cfs. See Figure 27.

Table 5: Peak flows for Olney Creek at SR 166

Mean recurrence interval (MRI)	Basin Scaled KPUD Gage (cfs)	USGS regression equation (Region 3) (cfs)	Regression equations predicted interval, lower 90% confidence level (percent)	Regression equations predicted interval upper 90% confidence level (percent)
2	**54**	39	20	77
10	**91**	76	37	157
25	**-**	96	45	205
50	**121**	110	50	243
100	**134**	126	56	284
500	**164**	163	67	399
2080 predicted 100	**203**	191	NA	NA

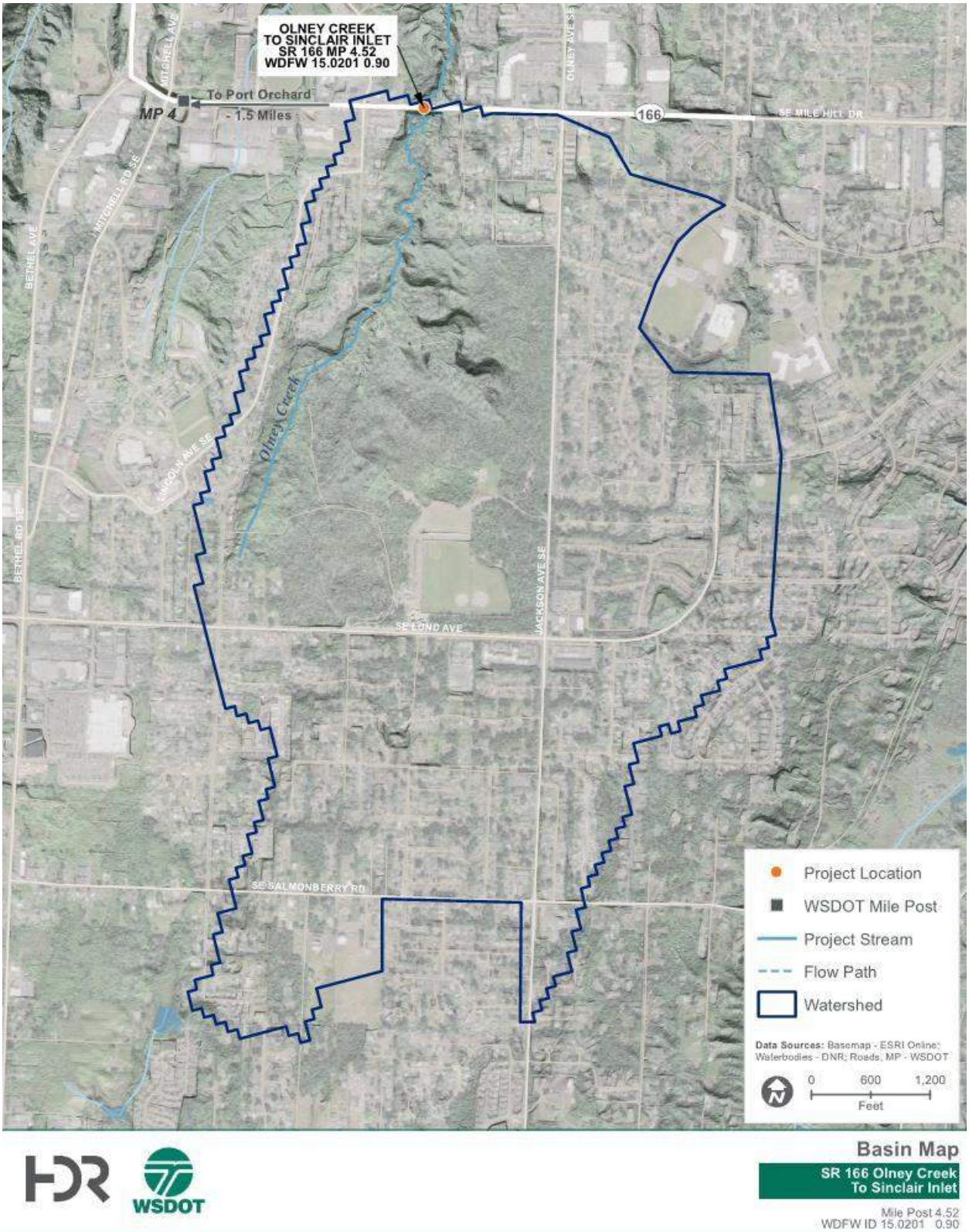


Figure 26: Basin map

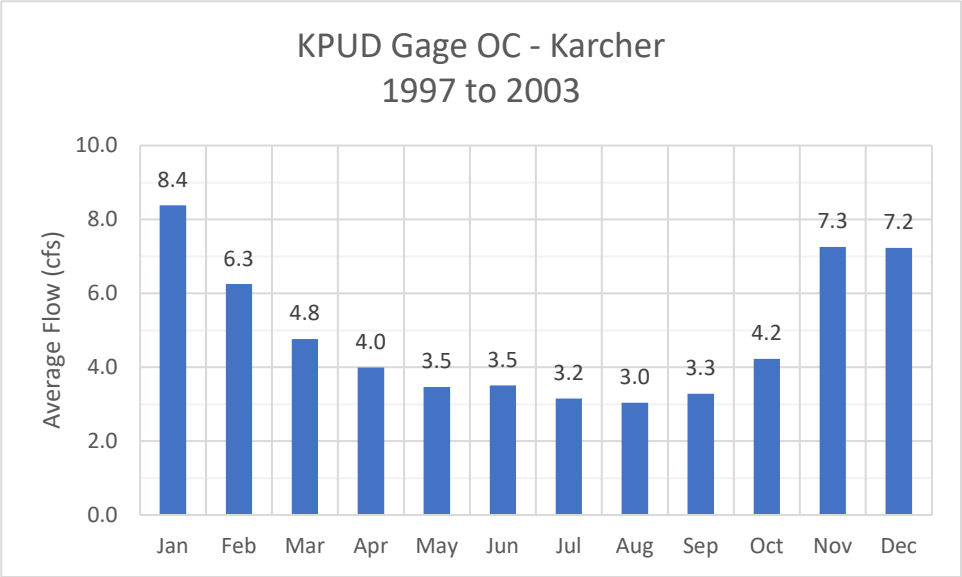


Figure 27: Average flow summary from at KPUD Olney Creek Gage

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed SR 166 Olney Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3.0 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.9 (Aquaveo 2021).

Three scenarios were analyzed for determining stream characteristics for Olney Creek with the SRH-2D models: (1) existing conditions with the 4-foot-high by 4-foot-wide, four-sided concrete box culvert, (2) estimated natural conditions, and (3) future conditions with the proposed hydraulic opening.

4.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

4.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the Project Engineer's Office (PEO), which were developed from topographic surveys provided by WSDOT in March 2021. The survey data were supplemented with LiDAR data (USGS and Quantum Spatial 2018). Proposed channel geometry was developed from the proposed grading surface created by HDR. All survey and LiDAR information is referenced against the North American Vertical Datum of 1988 (NAVD88), feet (U.S. Survey).

4.1.2 Model Extent and Computational Mesh

The hydraulic model upstream and downstream extents start and end within the topographic survey data. The detailed survey data are stitched into the LiDAR to incorporate more area adjacent to the channel. The model boundary starts approximately 160 feet upstream of the existing culvert inlet and ends approximately 210 feet downstream of the existing culvert outlet, measured along the channel centerline. The computational mesh elements are a combination of patched (quadrilateral) and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain. The existing mesh covers a total area of 94,377 square feet (SF), with 14,938 quadrilateral and 3,054 triangular elements (Figure 28). Natural conditions have a mesh that covers a total area of 94,377 SF, with 30,057 quadrilateral and 5,583 triangular elements (Figure 29). The proposed mesh covers a total area of 89,738 SF, with 26,186 quadrilateral and 5,566 triangular elements (Figure 30).

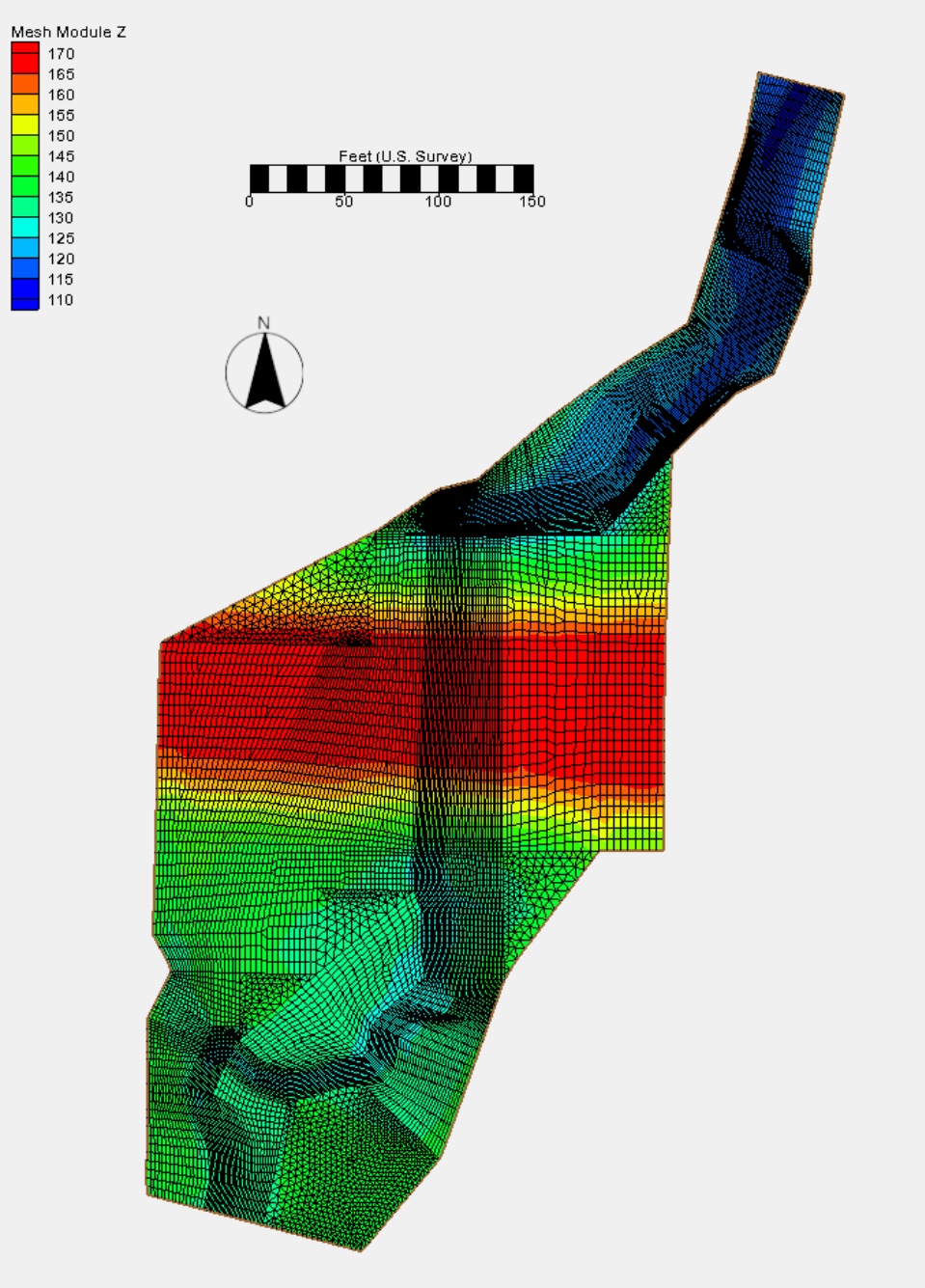


Figure 28: Existing-conditions computational mesh with underlying terrain

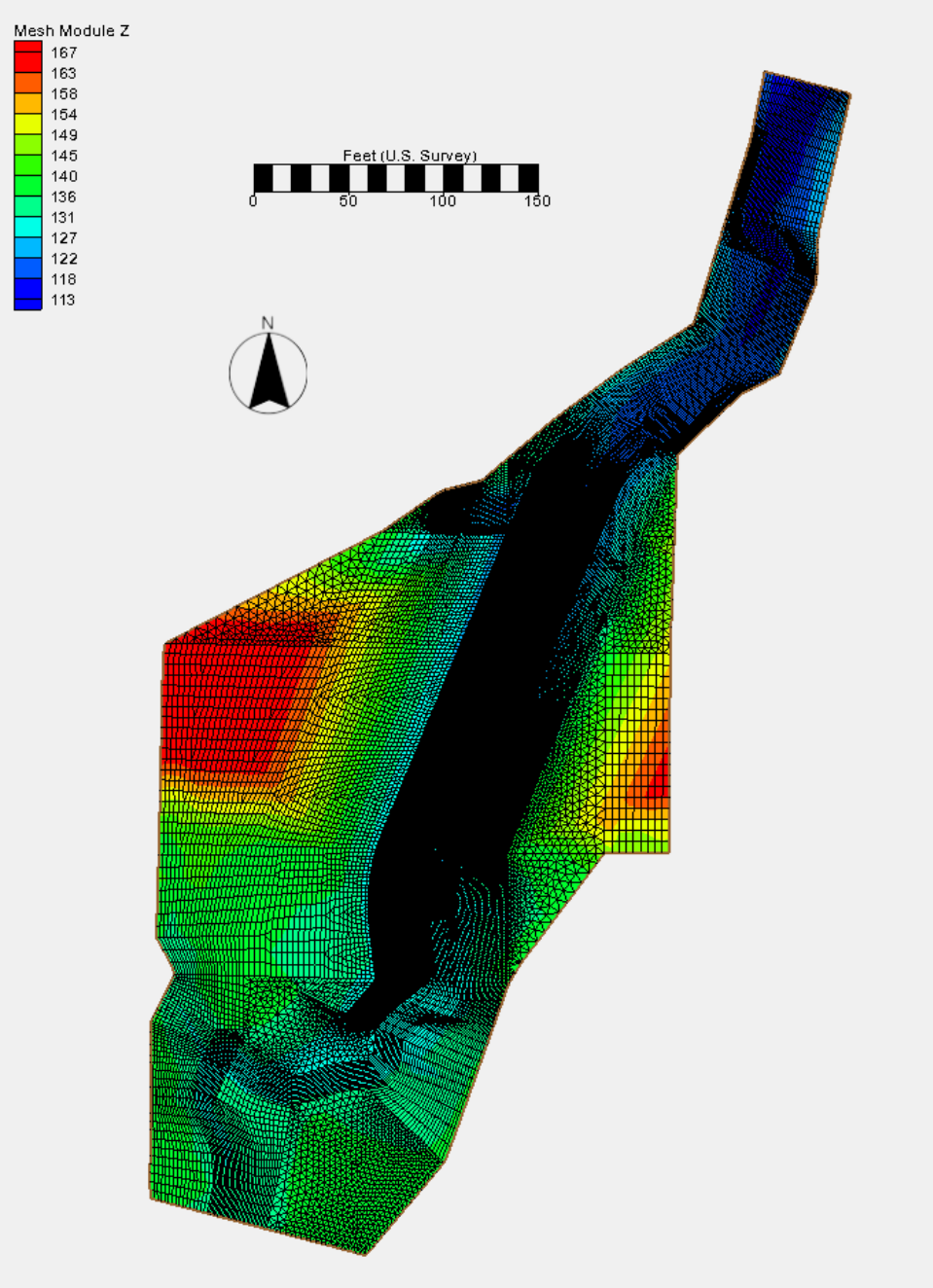


Figure 29: Natural-conditions computational mesh with underlying terrain

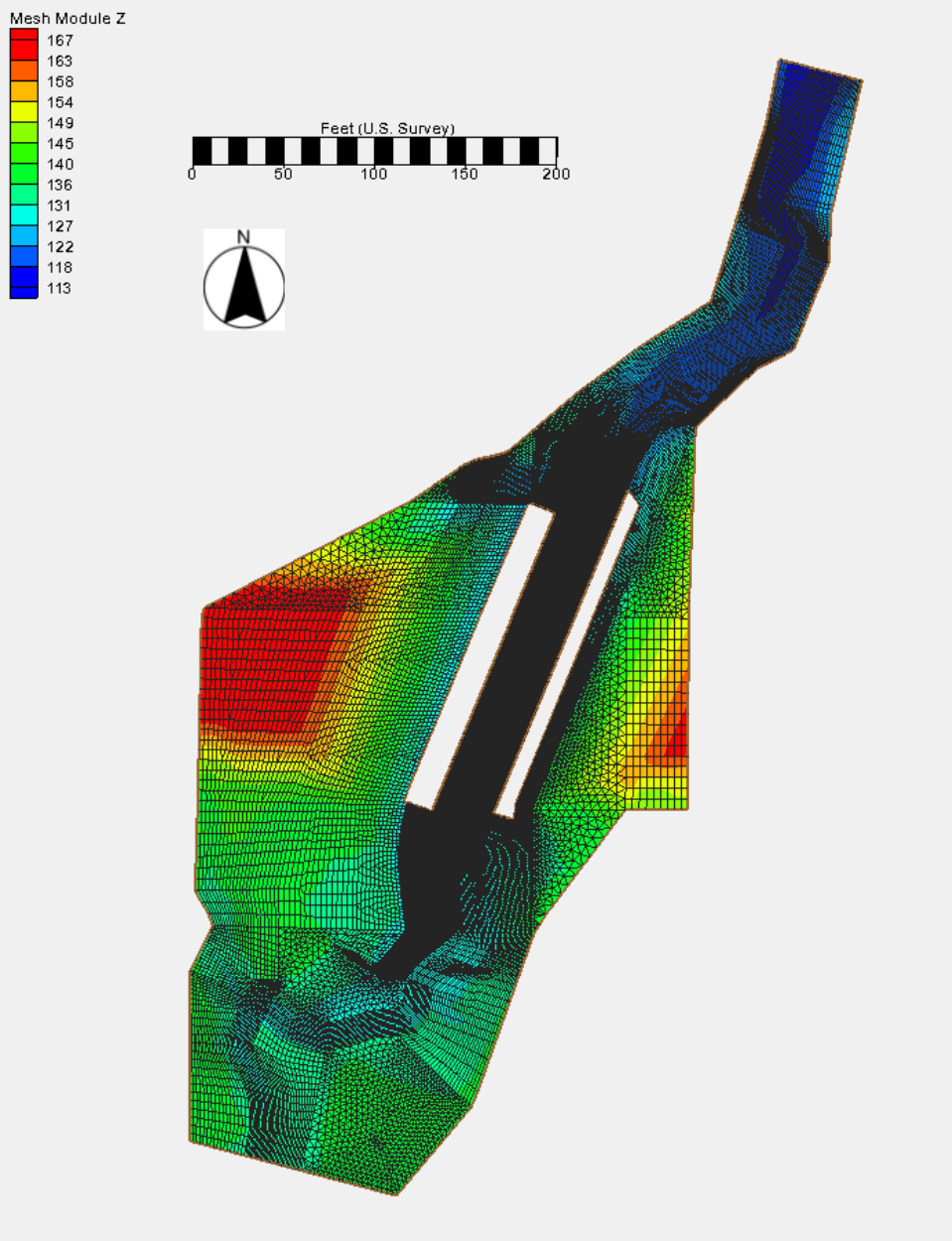


Figure 30: Proposed-conditions computational mesh with underlying terrain

4.1.3 Materials/Roughness

Manning's n values, estimated based on site observations, aerial photography, and standard engineering values (Chow 1959), are summarized in Table 6. The roadway surface was assigned a roughness value of 0.020. Upland areas and the road fill slope were given a roughness value of 0.060 as they contain less dense natural vegetation. Two channel roughness values were used based on channel complexity and presence of in-channel LWM. A value of 0.040 was used in the channel for the upstream reach and 0.055 was used for the downstream reach. Two floodplain roughness values were used based on density of understory vegetation. The upstream reach and upper half of the downstream reach were assigned a value of 0

.100 and the lower half of the downstream reach was assigned a value of 0.120. A short section in the downstream reach (near STA 3+10) was assigned a roughness value of 0.20 because of two large channel-spanning wood pieces that partially block flow above water depths of approximately 1 foot. The proposed channel was assigned a roughness value of 0.055 and the proposed floodplain was assigned a roughness value of 0.10. See Figure 31, Figure 32, and Figure 33 for a spatial distribution of hydraulic roughness coefficient values for existing-conditions, natural-conditions, and proposed-conditions, respectively.

Table 6: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Land cover type	Manning's n
Impervious	0.020
Road fill slope/upland	0.060
Channel 1	0.040
Channel 2	0.055
Floodplain 1	0.100
Floodplain 2	0.120
Channel-spanning logs	0.200
Proposed channel	0.055

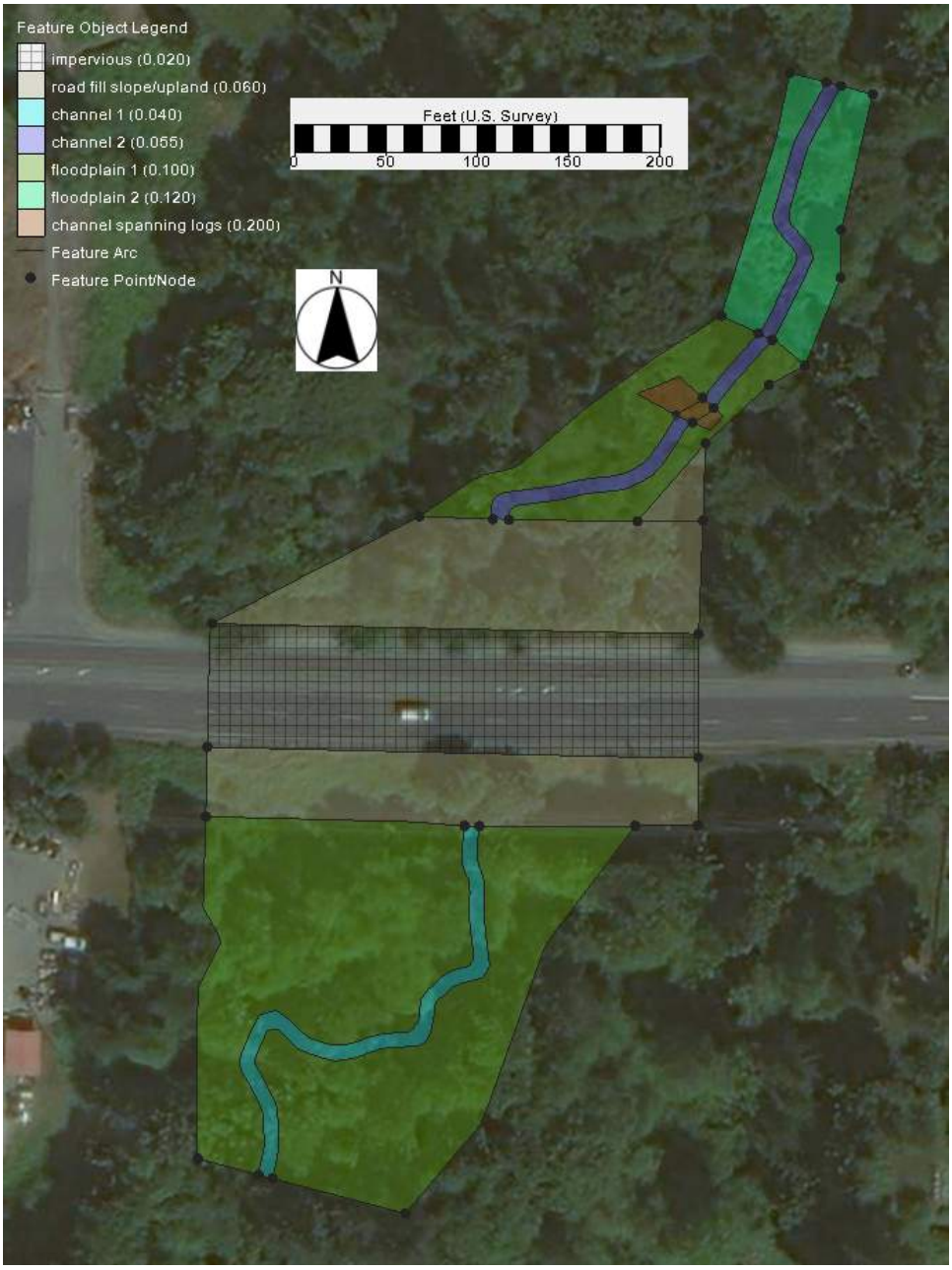


Figure 31: Spatial distribution of existing-conditions roughness values in SRH-2D model

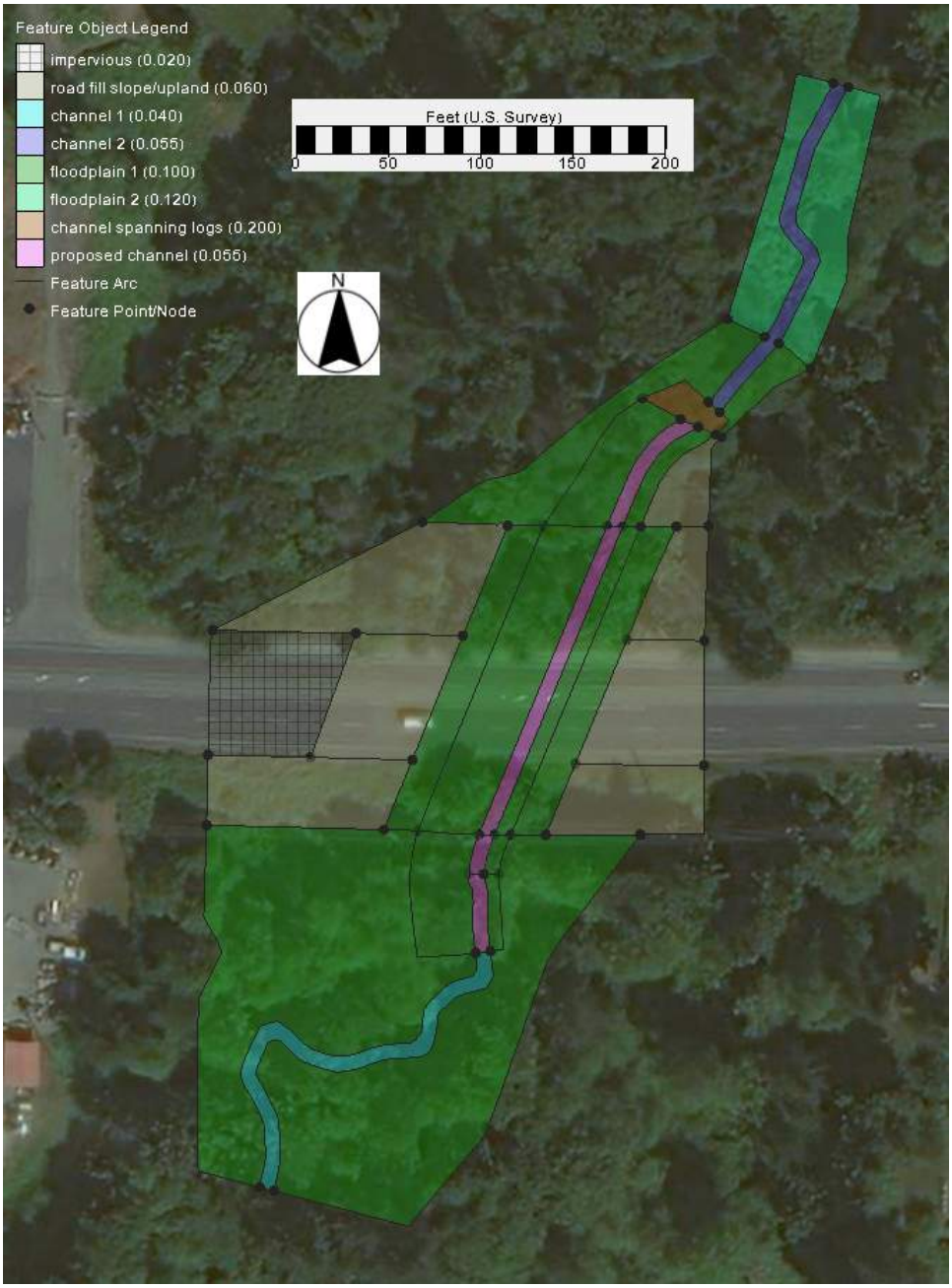


Figure 32: Spatial distribution of natural-conditions roughness values in SRH-2D model

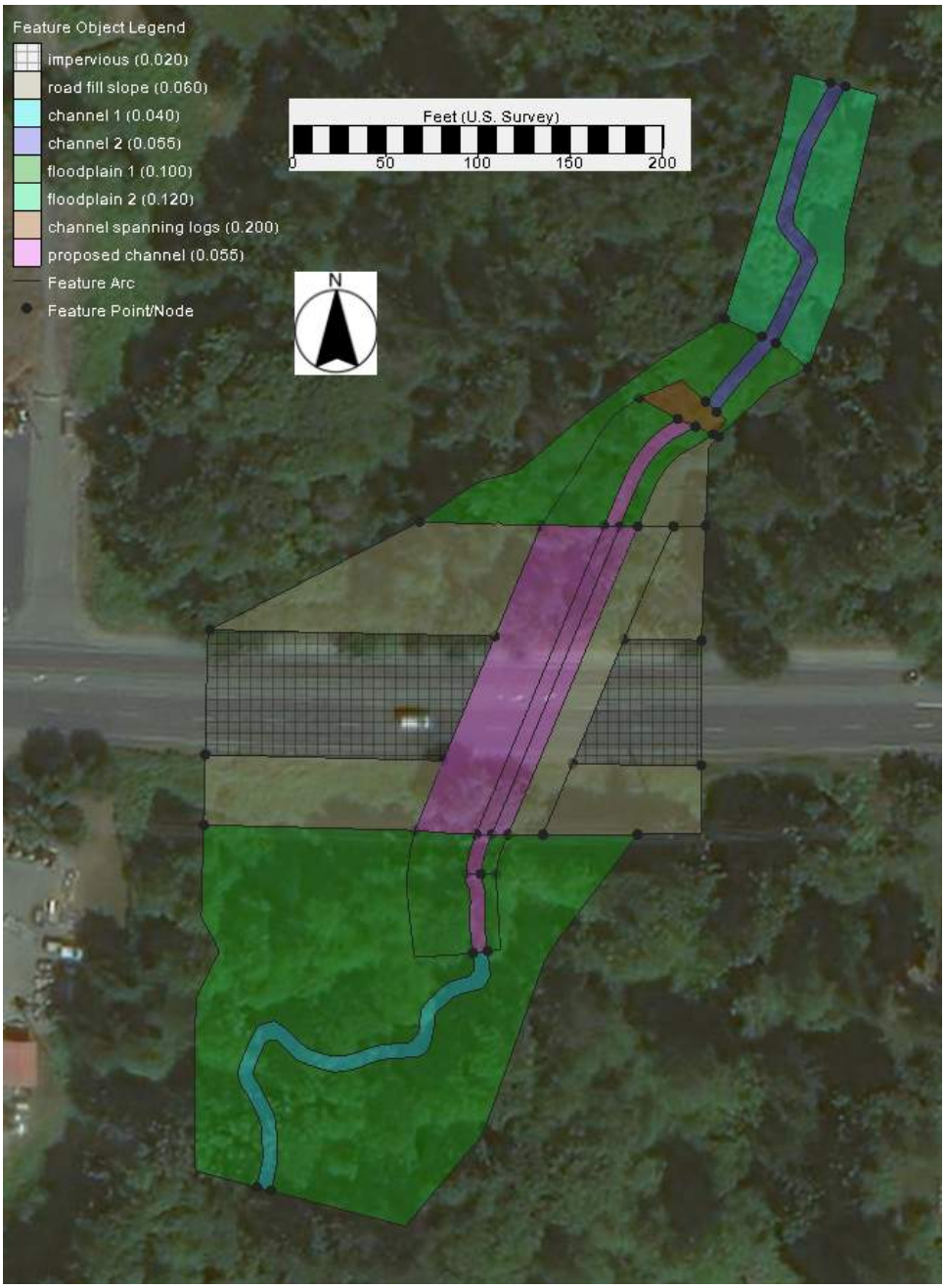


Figure 33: Spatial distribution of proposed-conditions roughness values in SRH-2D model

4.1.4 Boundary Conditions

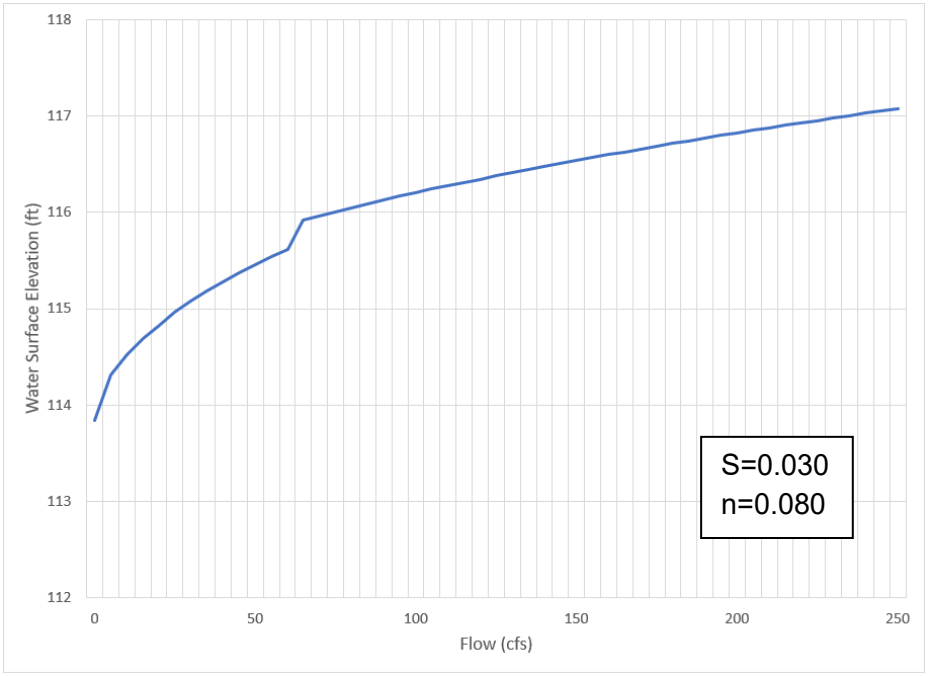
Model simulations were performed using constant discharges for the 2-year, 100-year, 2080 projected 100-year, and 500-year peak discharges summarized in Section 3. External boundary conditions were applied at the upstream and downstream extents of the model domain and remained the same between the existing-, natural-, and proposed-conditions runs. A constant flow rate was specified at the upstream external boundary condition, while a normal depth rating curve was specified at the downstream boundary. The constant flow rates for the events are equa

l to those presented in Section 3 for each of the peak discharges modeled. The downstream normal depth boundary condition rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 3 percent based on local survey data and a composite roughness of 0.080 (see Figure 34). A boundary sensitivity analysis was done with slopes varying between 2.8 and 3.2 percent with a constant roughness value. The varying boundary conditions result in water surface elevations (WSELs) that converge outside the extents of the proposed channel grading.

An HY-8 internal boundary condition was specified in the existing-conditions model to represent the existing culvert crossing. The existing crossing was modeled as a 4-foot-wide by 4-foot-tall concrete box culvert within HY-8. A Manning's roughness of 0.015 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel. HY-8 inputs are detailed in Figure 35.

Model simulations were run for a sufficiently long duration until the results stabilized across the model domain. Existing-conditions, natural-conditions, and proposed boundary conditions are depicted in Figure 36, Figure 37, and Figure 38, respectively.

The proposed structure was modeled by specifying voids in the mesh to represent the locations of the abutments or walls. Symmetry (slip) boundary conditions were specified in the proposed-conditions model to represent the faces of the proposed structure. By default, SRH-2D uses a no-slip boundary at the boundaries, meaning that the velocity is equal to 0 feet per second (ft/s) at the structure face. Using a slip boundary allows for velocity along the face of the structure, more accurately representing real conditions.



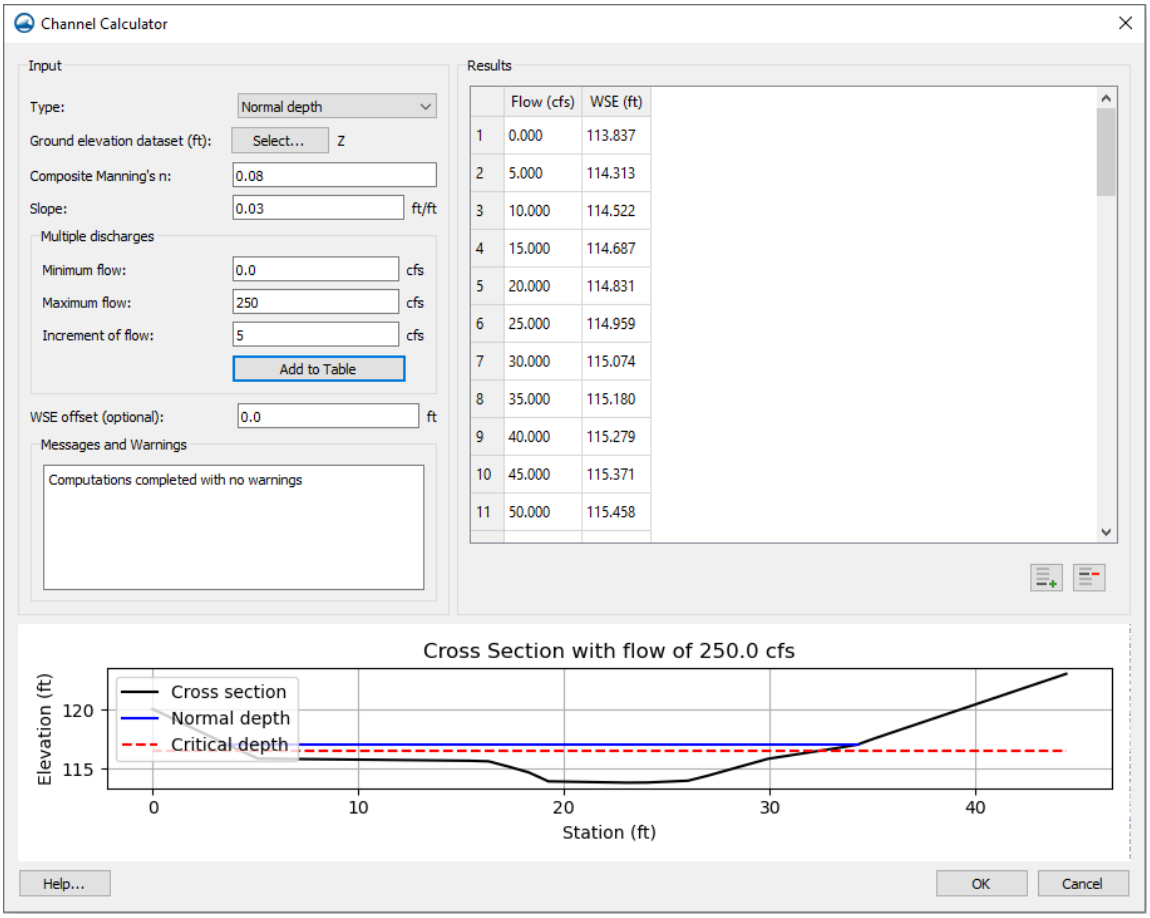


Figure 34: Downstream normal depth rating curve for Exit H for all boundary conditions

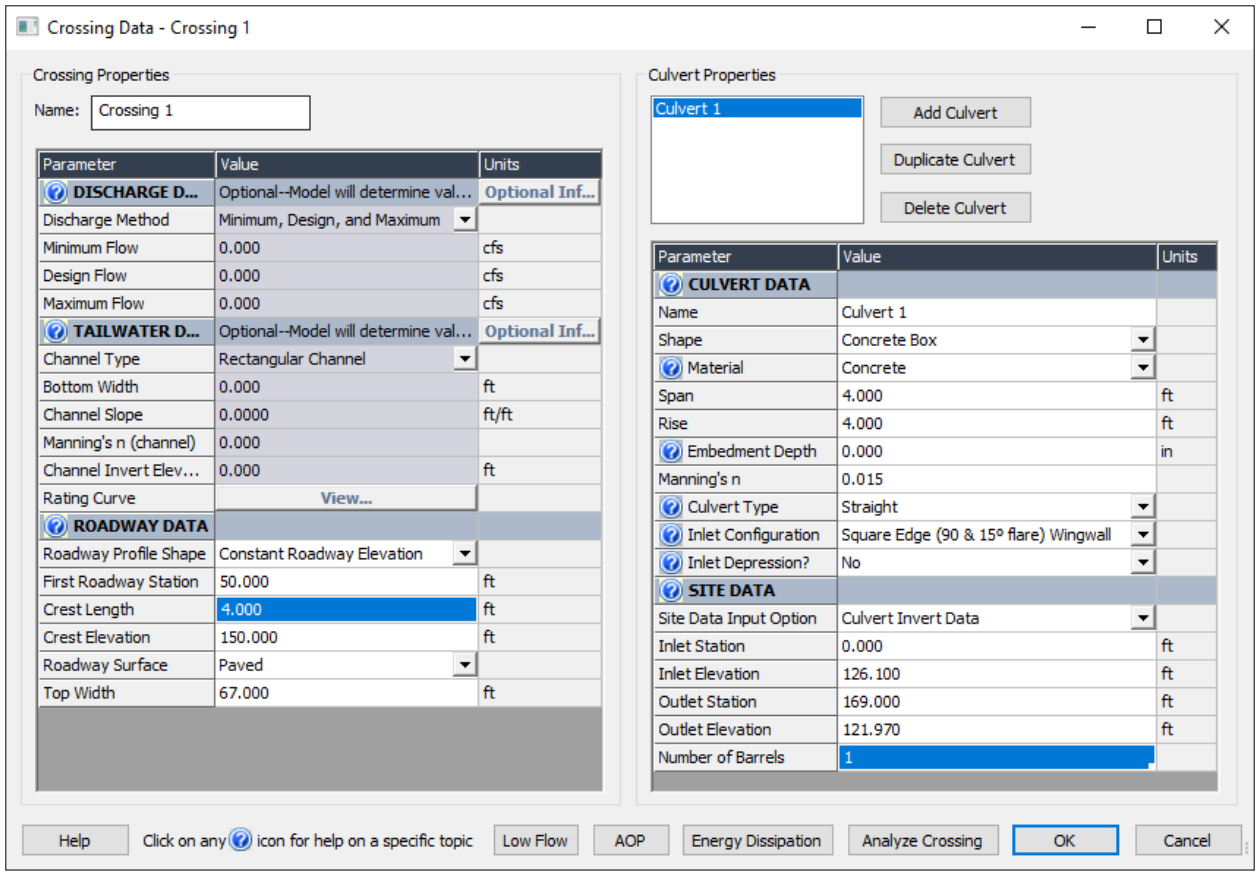


Figure 35: HY-8 existing-condition culvert parameters

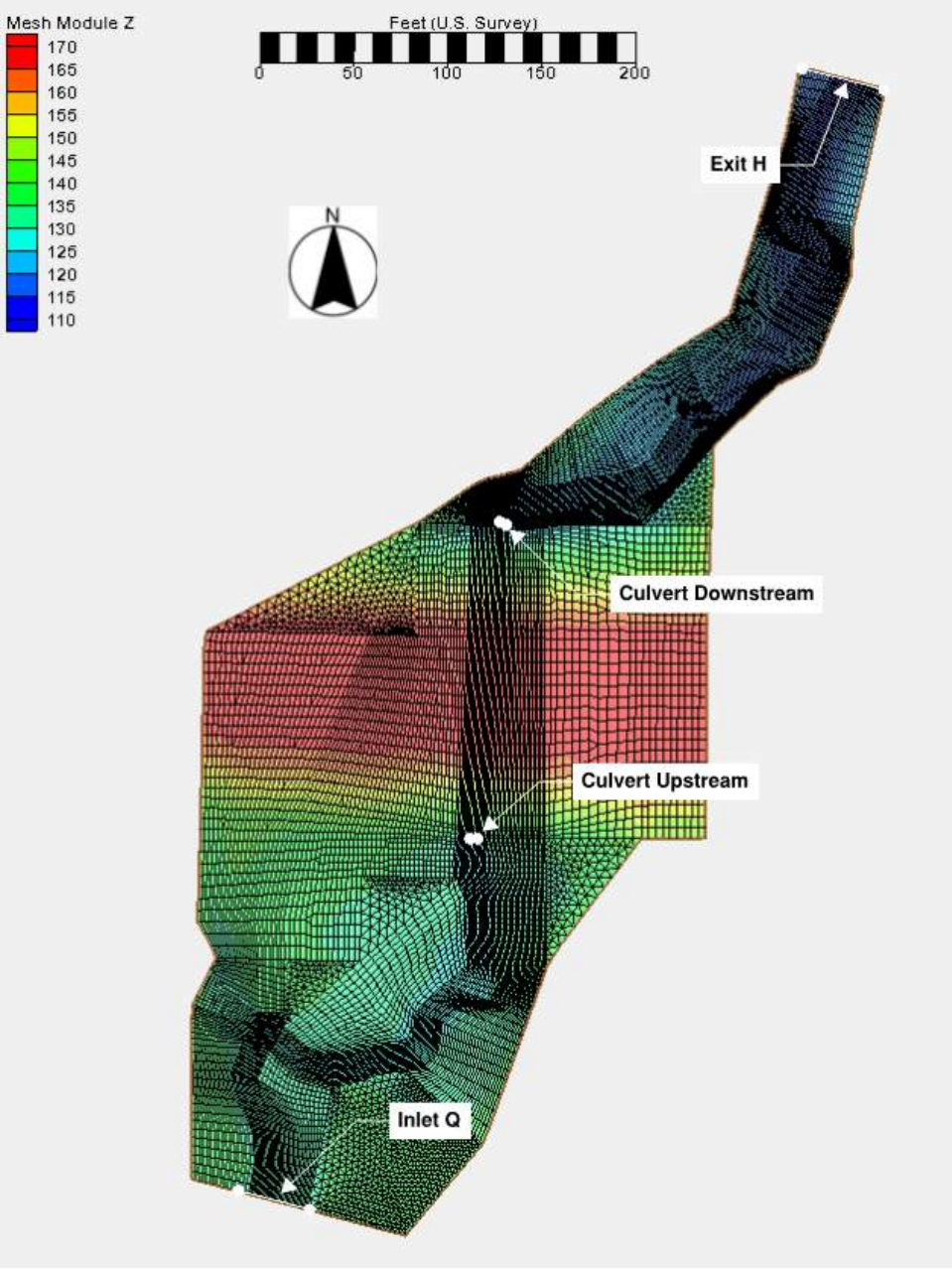


Figure 36: Existing boundary conditions

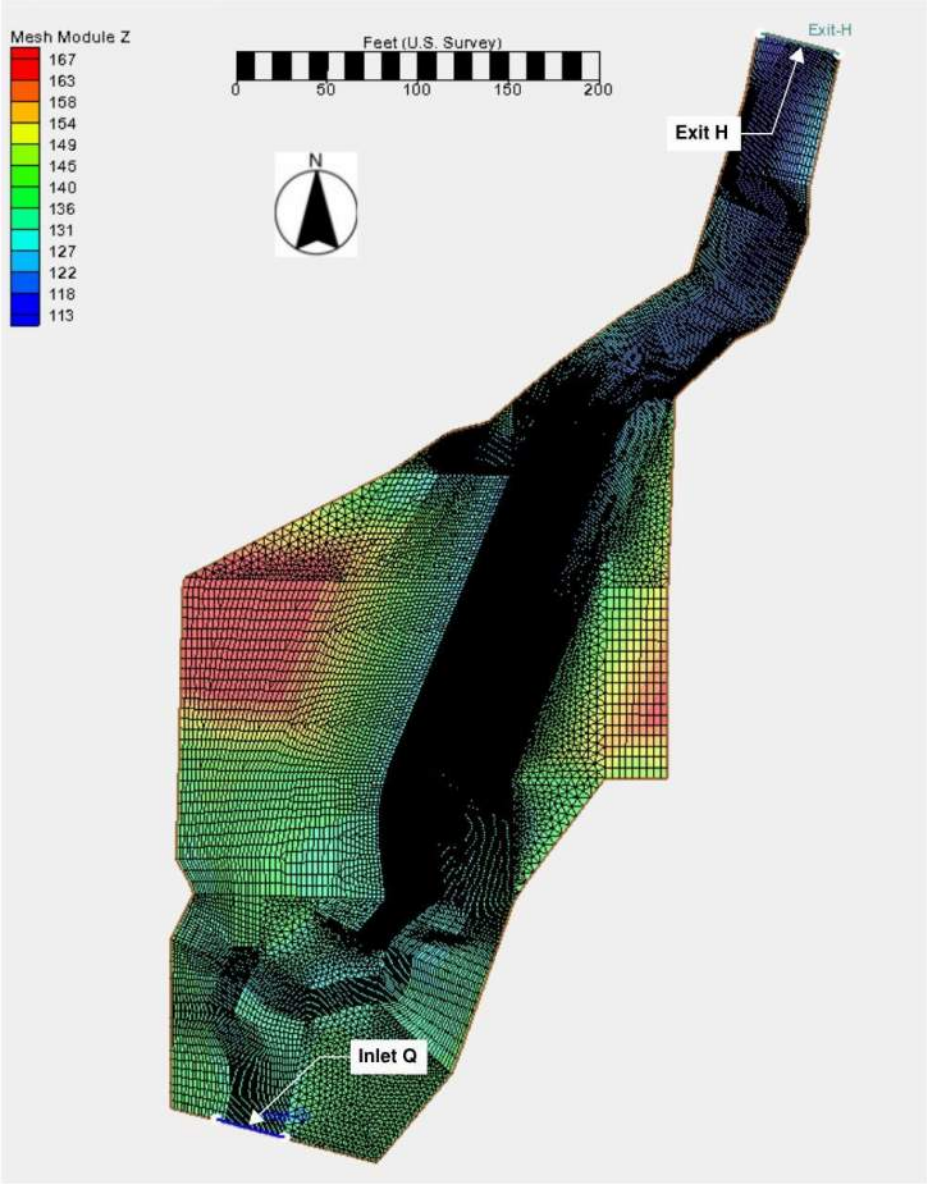


Figure 37: Natural-conditions boundary conditions

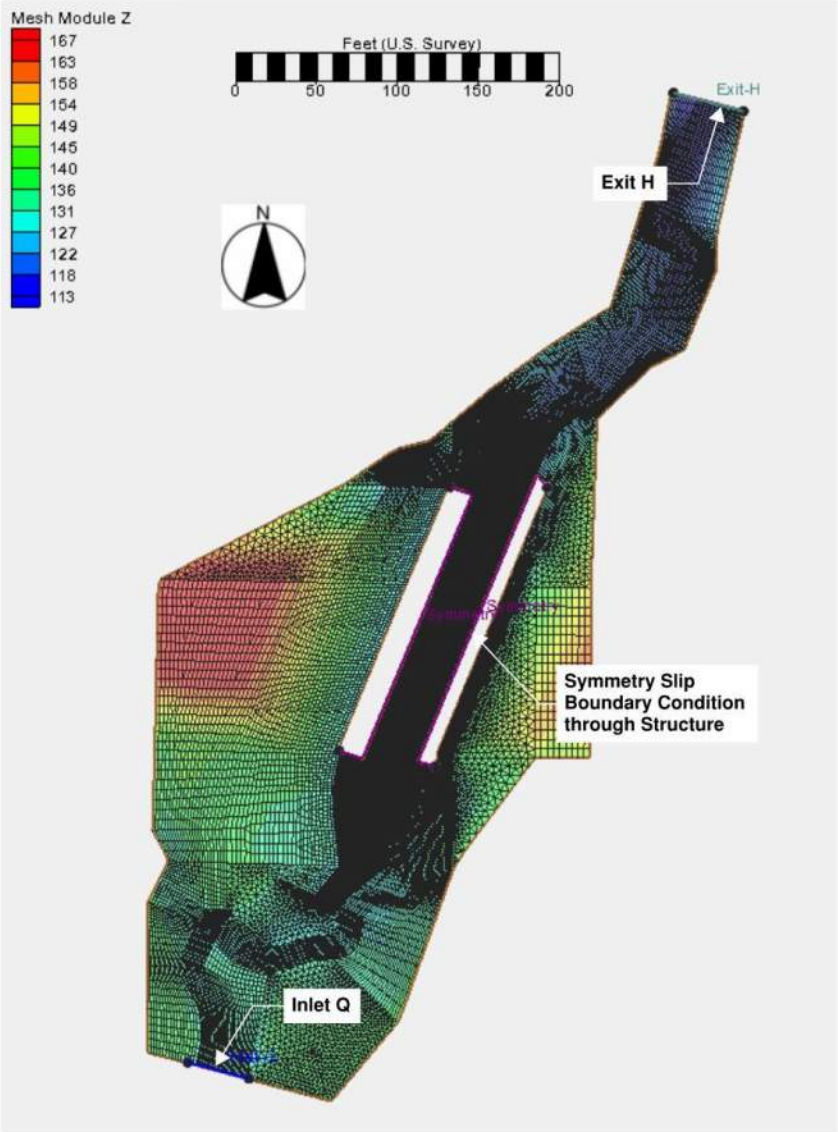


Figure 38: Proposed boundary conditions

4.1.5 Model Run Controls

Model controls were different between existing-, natural-, and proposed-conditions models. All model simulations were run for a sufficiently long duration until the results stabilized across the model domain, which was 1.5 hours for the existing-conditions and 0.5 hour for the natural-conditions and proposed-conditions models. The existing-conditions model controls were set at:

- **Start time:** 0 hour
- **Time step:** 1.0 second
- **End time:** 1.5 hours

- **Initial condition:** dry

The natural-conditions and proposed-conditions model controls were set at:

- **Start time:** 0 hour
- **Time step:** 1.0 second
- **End time:** 0.5 hour
- **Initial condition:** dry

4.1.6 Model Assumptions and Limitations

The SRH-2D hydraulic model was developed to determine the minimum hydraulic structure opening, establish the proposed structure low chord elevation (and associated freeboard), and characterize hydraulic parameters used to design the crossing. The use of a constant inflow rate is an appropriate assumption to meet the model objectives. Using a constant inflow rate provides a conservative estimate of inundation extents and WSEL associated with a given peak flow, which is used to determine the structure size and low chord.

Using the approach described in this study, each scenario is run for a sufficient time to fill storage areas and for WSELs to stabilize until flow upstream equals flow downstream. This modeling method does not account for the attenuation of peak flows between the actual upstream and downstream hydrographs, in particular the storage created by the existing undersized culvert. An unsteady simulation could be used to route a hydrograph through the model to estimate peak flow attenuation for existing and proposed conditions. During an unsteady simulation, the areas upstream of the existing culvert would act as storage and, as a result, the flow downstream of the crossing would likely be less than the current design peak flow event. Estimates of the downstream increases to WSEL and flow based on the constant inflow model results may then underestimate the change in downstream flood impacts. An unsteady analysis is outside the current scope of this preliminary study but could be considered at a later stage of design. Therefore, the changes to the peak flow rate downstream of the project cannot be quantified with this approach.

The model results and recommendations in this PHD Report are based on the conditions of the project site and the associated watershed at the time of this study. Any modifications to the site, man-made or natural, could alter the analysis, findings, and recommendations contained herein and could invalidate the analysis, findings, and recommendations. Site conditions, completion of upstream or downstream projects, upstream or downstream land use changes, climate changes, vegetation changes, maintenance practice changes, or other factors may change over time. Additional analysis or updates may be required in the future as a result of these changes.

4.2 Existing-Conditions Model Results

Hydraulic results were summarized and compared at common locations for the existing-, natural-, and proposed-conditions simulations (Figure 39). Eight cross sections were selected to give representation of the geometry on site: one in the selected reference reach upstream, two otherwise upstream, one upstream of the culvert inlet, one immediately downstream of the culvert outlet, and two downstream. The cross section immediately downstream of the culvert outlet was moved to the middle of the road for the natural- and proposed-conditions simulations. Each

was also given a letter notation of A through H so that despite changes in stationing between the existing and proposed conditions, each section will be denoted by the same letter for comparison with the only exception being cross section E, which moved as described above. The cross sections (D and F) upstream and downstream of the culvert inlet and outlet show how the results change after installing the proposed structure.

Because the proposed grading realigns the stream, the existing- and natural-/proposed-conditions models use different stationing for reporting results. The existing- and natural-/ proposed-conditions cross-section locations and orientations were selected to cross their respective stream thalweg at identical points. The existing-conditions cross sections and alignment used for reporting are displayed in Figure 39 and Figure 40, respectively.

Cross sections in Table 7 are used to summarize the hydraulic results for Olney Creek. Under existing conditions, the culvert is inlet controlled and causes backwater upstream of the inlet during the 2-, 100-, and 500-year events simulated under SR 166 (Figure 41). Pressure flow in the existing culvert first occurs during the 2-year event. The existing roadway was not overtopped within the range of flow events modeled. A typical section with WSELs is depicted in Figure 42, and all cross sections are provided in Appendix C.

The culvert backwater affects results for the 100-year and 500-year flows for nearly the entire upstream reach. In the upstream reaches velocities range from 2.92 ft/s during the 2-year event to 5.23 ft/s for the 100-year event. In the downstream reaches, average channel velocities range from 2.7 ft/s during the 2-year event to 6.32 ft/s during the 100-year event. Floodplain and main channel velocities are also summarized in Table 8. Shear values in the upstream reach range from 0.60 pound per square foot (lb/SF) during the 2-year event to 2.05 lb/SF during the 100-year event. Shear values on the downstream reach range from 1.08 lb/SF at the 2-year event to 3.88 lb/SF during the 500-year event. The largest velocities occur at the culvert outlet (Figure 43). For the 2-year flow upstream of the culvert backwater effect, the depths range from 1.53 to 1.60 feet. Depths in the downstream reach range from 1.44 feet at the 2-year event to 3.73 feet during the 500-year event.

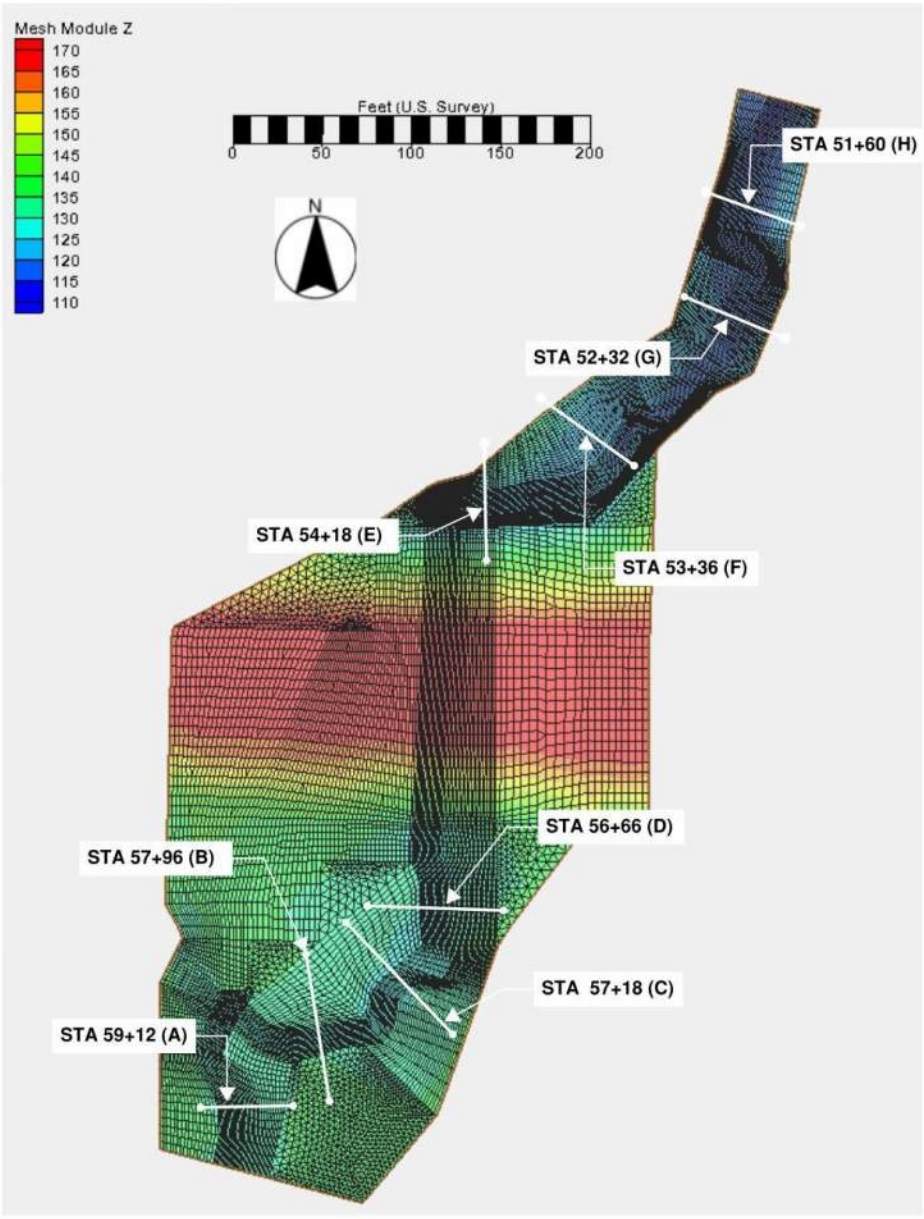


Figure 39: Locations of cross sections used for existing-conditions results reporting

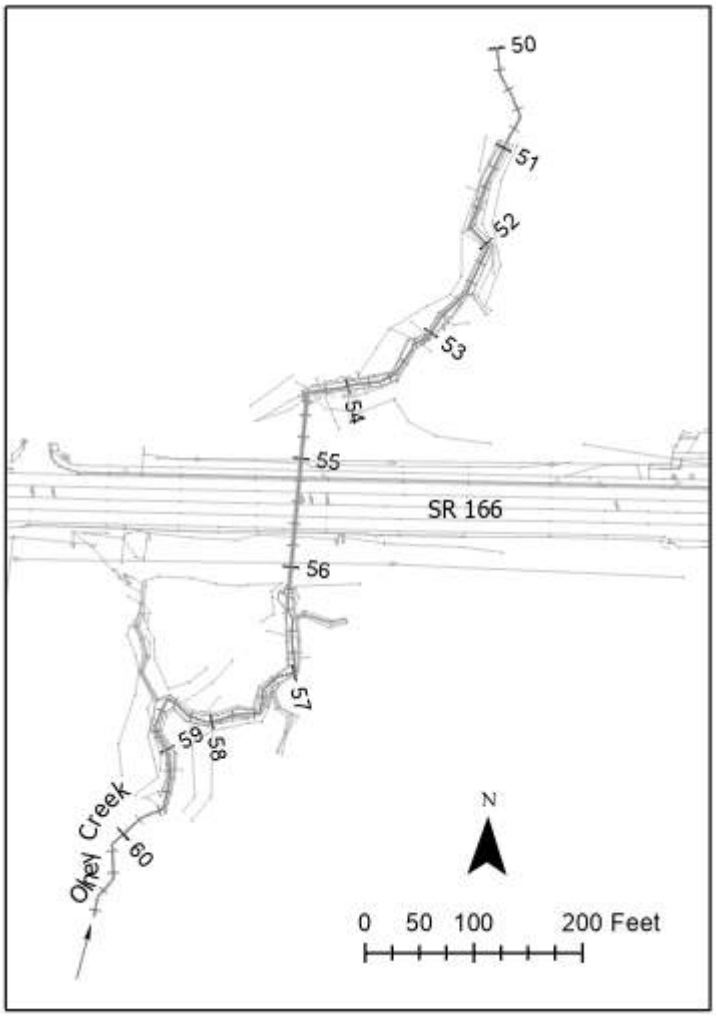


Figure 40: Longitudinal profile stationing for existing conditions

Table 7: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSEL (ft)	DS 51+60 (H)	116.89	117.87	118.14
	DS 52+32 (G)	118.92	119.81	120.04
	DS 53+36 (F)	121.24	122.28	122.56
	DS 54+18 (E)	123.31	124.25	124.52
	US 56+66 (D)	129.26	131.88	133.45
	US 57+18 (C)	130.01	132.00	133.49
	US 57+96 (B)	130.86	132.14	133.52
	US 59+12 (A)	132.42	133.10	133.69
Max depth (ft)	DS 51+60 (H)	1.44	2.43	2.70
	DS 52+32 (G)	1.74	2.63	2.86
	DS 53+36 (F)	2.40	3.45	3.73
	DS 54+18 (E)	1.63	2.56	2.83
	US 56+66 (D)	1.82	4.44	6.01
	US 57+18 (C)	1.79	3.77	5.25
	US 57+96 (B)	1.60	2.88	4.25
	US 59+12 (A)	1.53	2.19	2.78
Average velocity (ft/s)	DS 51+60 (H)	4.34	5.40	5.56
	DS 52+32 (G)	2.70	4.01	4.34
	DS 53+36 (F)	3.99	5.15	5.29
	DS 54+18 (E)	4.76	6.32	6.67
	US 56+66 (D)	3.15	1.90	1.24
	US 57+18 (C)	2.92	1.60	0.97
	US 57+96 (B)	3.26	3.20	1.77
	US 59+12 (A)	3.98	5.23	4.55
Average shear (lb/SF)	DS 51+60 (H)	2.30	3.32	3.50
	DS 52+32 (G)	1.08	2.28	2.64
	DS 53+36 (F)	1.51	2.16	2.23
	DS 54+18 (E)	2.26	3.56	3.88
	US 56+66 (D)	0.64	0.21	0.09
	US 57+18 (C)	0.60	0.17	0.06
	US 57+96 (B)	0.89	0.84	0.27
	US 59+12 (A)	1.21	2.05	1.52

Main channel extents were approximated by inspection of the terrain surface.

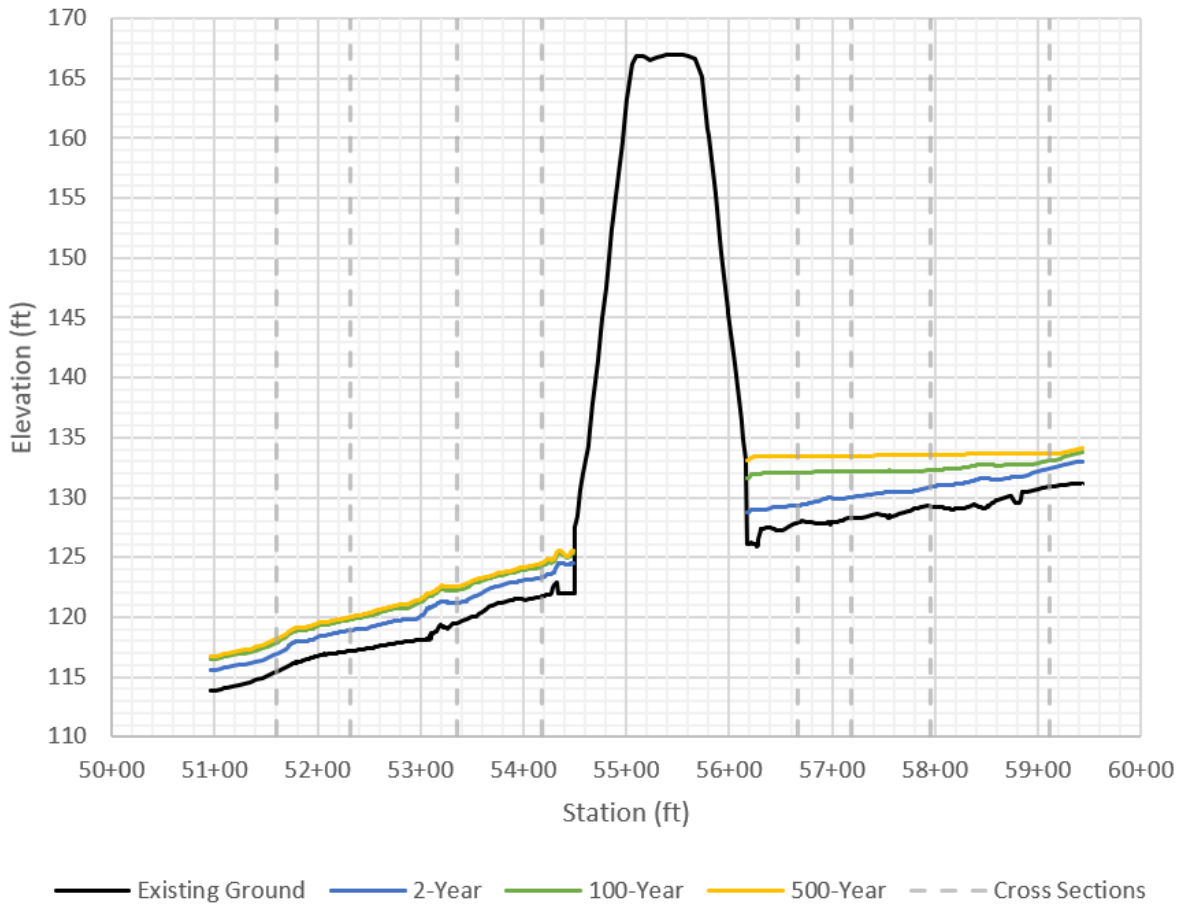


Figure 41: Existing-conditions water surface profiles

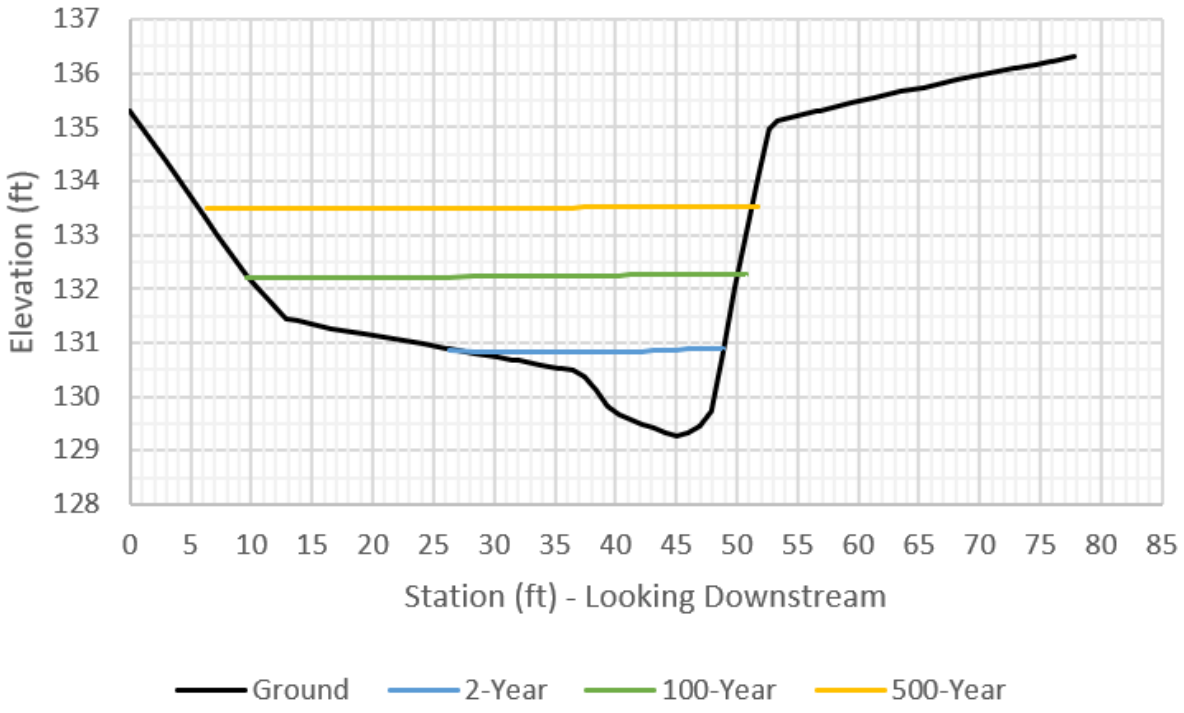


Figure 42: Typical upstream existing channel cross section (STA 57+96)

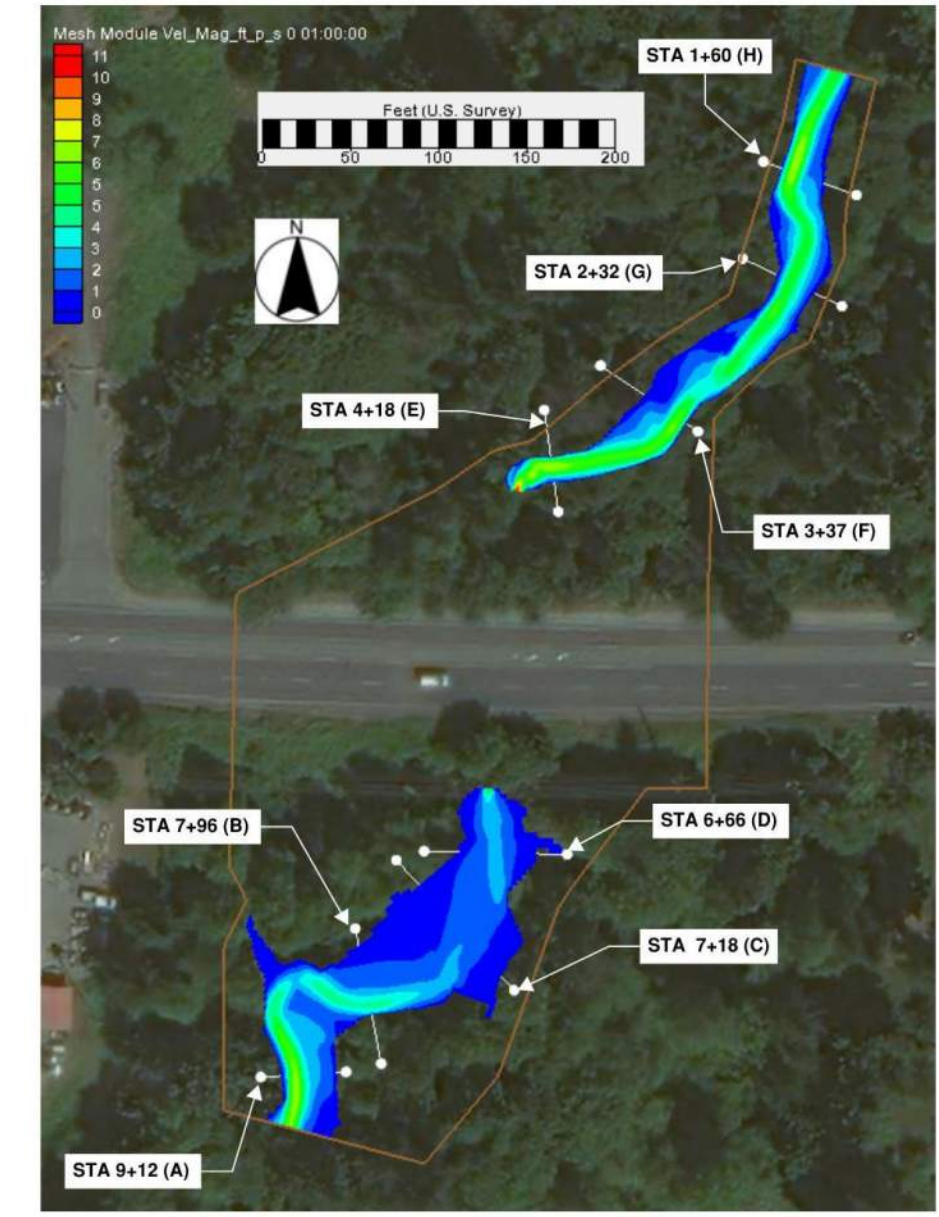


Figure 43: Existing-conditions 100-year velocity map with cross-section locations

Table 8: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 51+60 (H)	2.18	5.40	1.64
DS 52+32 (G)	1.12	4.01	1.09
DS 53+36 (F)	1.04	5.15	3.03
DS 54+18 (E)	2.93	6.32	2.63
US 56+66 (D)	0.94	1.90	0.68
US 57+18 (C)	0.82	1.60	0.60
US 57+96 (B)	1.08	3.20	1.06
US 59+12 (A)	1.67	5.23	1.80

a. Right overbank (ROB)/left overbank (LOB) locations were approximated from inspecting the survey and 2-year top width.

4.3 Natural Conditions

The natural- and proposed-conditions cross sections and alignment used for reporting are displayed in Figure 44 and Figure 45, respectively. Cross sections in Table 9 are used to summarize the hydraulic results for Olney Creek. Figure 46 shows water surface profiles for the reach under natural conditions. All cross sections are provided in Appendix C.

Upstream of the crossing, velocities range from 4.11 ft/s to 5.28 ft/s during the 100-year event and 4.52 ft/s to 6.00 ft/s during the projected 2080 100-year event. In the downstream reaches, average channel velocities range from 4.01 ft/s to 5.40 ft/s during the 100-year event and from 4.72 ft/s to 5.75 ft/s during the projected 2080 100-year event. Floodplain and main channel velocities are also summarized in Table 10. Shear values in the upstream reach range from 1.17 lb/SF during the 100-year event to 2.94 lb/SF during the projected 2080 100-year event. Shear values on the downstream reach range from 2.01 lb/SF at the 100-year event to 3.69 lb/SF during the projected 2080 100-year event. The largest velocities occur at the most upstream reach at STA 8+65 (Figure 48). Upstream the depths range from 2.12 feet during the 100-year event to 2.82 feet during the projected 2080 100-year event. Depths in the downstream reach range from 2.43 feet at the 100-year event to 3.17 feet during the projected 2080 100-year event. There is no backwater at the crossing under natural or proposed conditions.

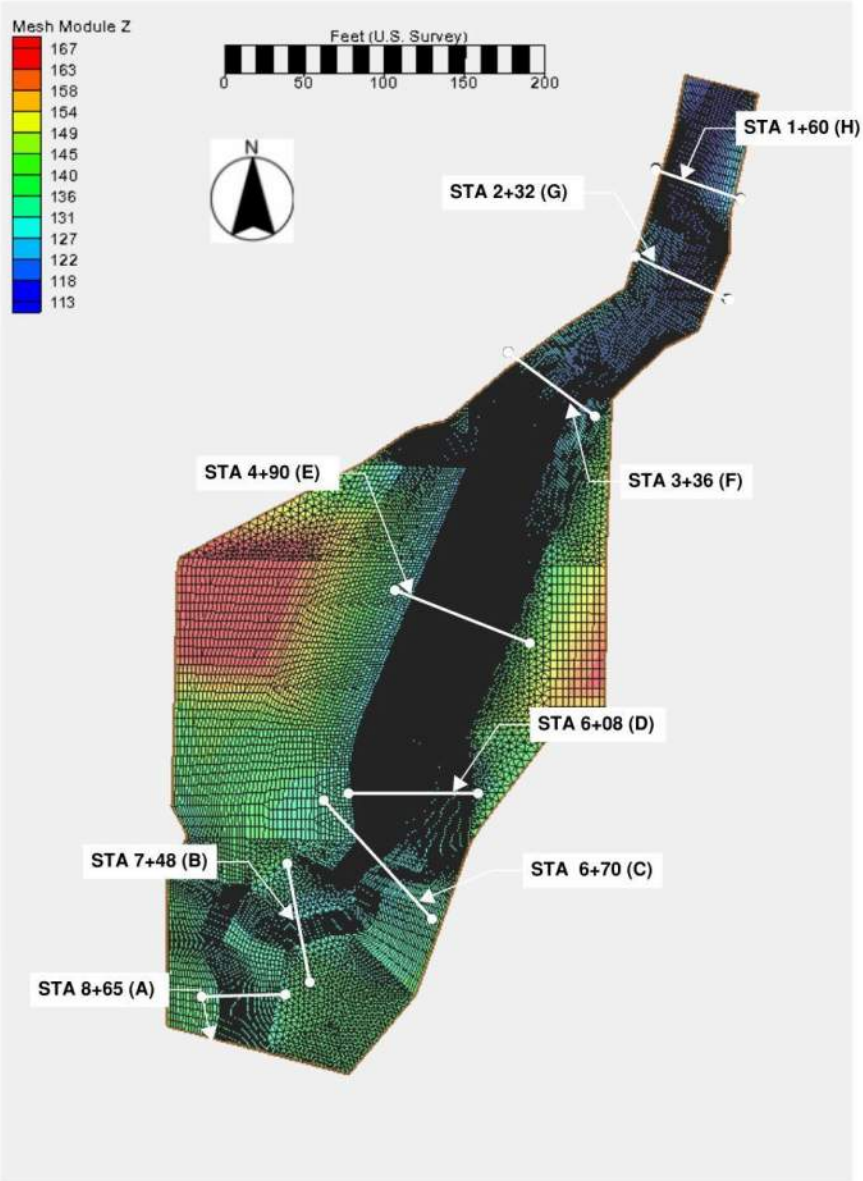


Figure 44: Locations of cross sections used for natural-conditions results reporting

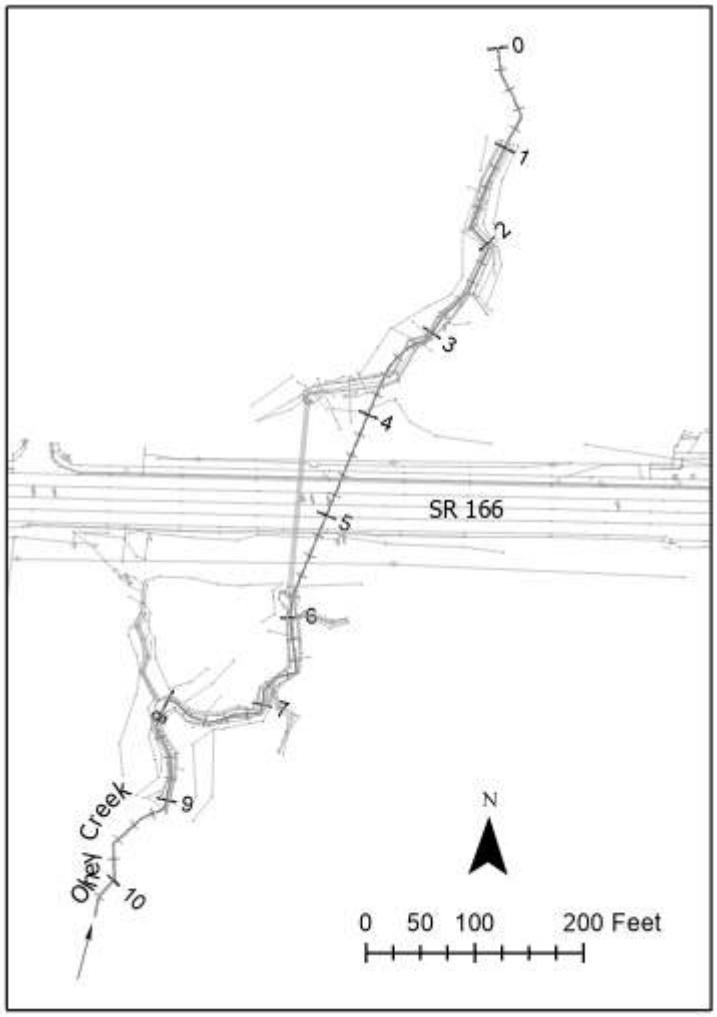


Figure 45: Longitudinal profile stationing for natural and proposed conditions

Table 9: Average main channel hydraulic results for natural conditions

Hydraulic parameter	Cross section	100-year	100-year 2080
Average WSEL (ft)	DS 1+60 (H)	117.87	118.46
	DS 2+32 (G)	119.81	120.32
	DS 3+36 (F)	122.31	122.87
	Structure 4+90 (E)	125.99	126.36
	US 6+08 (D)	129.21	129.57
	US 6+70 (C)	130.54	130.90
	US 7+48 (B)	131.64	132.06
	US 8+65 (A)	133.09	133.46
Max depth (ft)	DS 1+60 (H)	2.43	3.03
	DS 2+32 (G)	2.63	3.13
	DS 3+36 (F)	2.61	3.17
	Crossing 4+90 (E)	2.10	2.46
	US 6+08 (D)	2.12	2.49
	US 6+70 (C)	2.33	2.69
	US 7+48 (B)	2.4	2.82
	US 8+65 (A)	2.17	2.53
Average velocity (ft/s)	DS 1+60 (H)	5.40	5.75
	DS 2+32 (G)	4.01	4.72
	DS 3+36 (F)	4.61	5.22
	Structure 4+90 (E)	5.06	5.55
	US 6+08 (D)	5.14	5.57
	US 6+70 (C)	4.11	4.52
	US 7+48 (B)	4.34	4.79
	US 8+65 (A)	5.28	6.00
Average shear (lb/SF)	DS 1+60 (H)	3.32	3.69
	DS 2+32 (G)	2.28	3.09
	DS 3+36 (F)	2.01	2.47
	Structure 4+90 (E)	2.64	3.06
	US 6+08 (D)	2.64	2.94
	US 6+70 (C)	1.17	1.42
	US 7+48 (B)	1.56	1.94
	US 8+65 (A)	2.09	2.70

Main channel extents were approximated by inspection of the terrain surface.

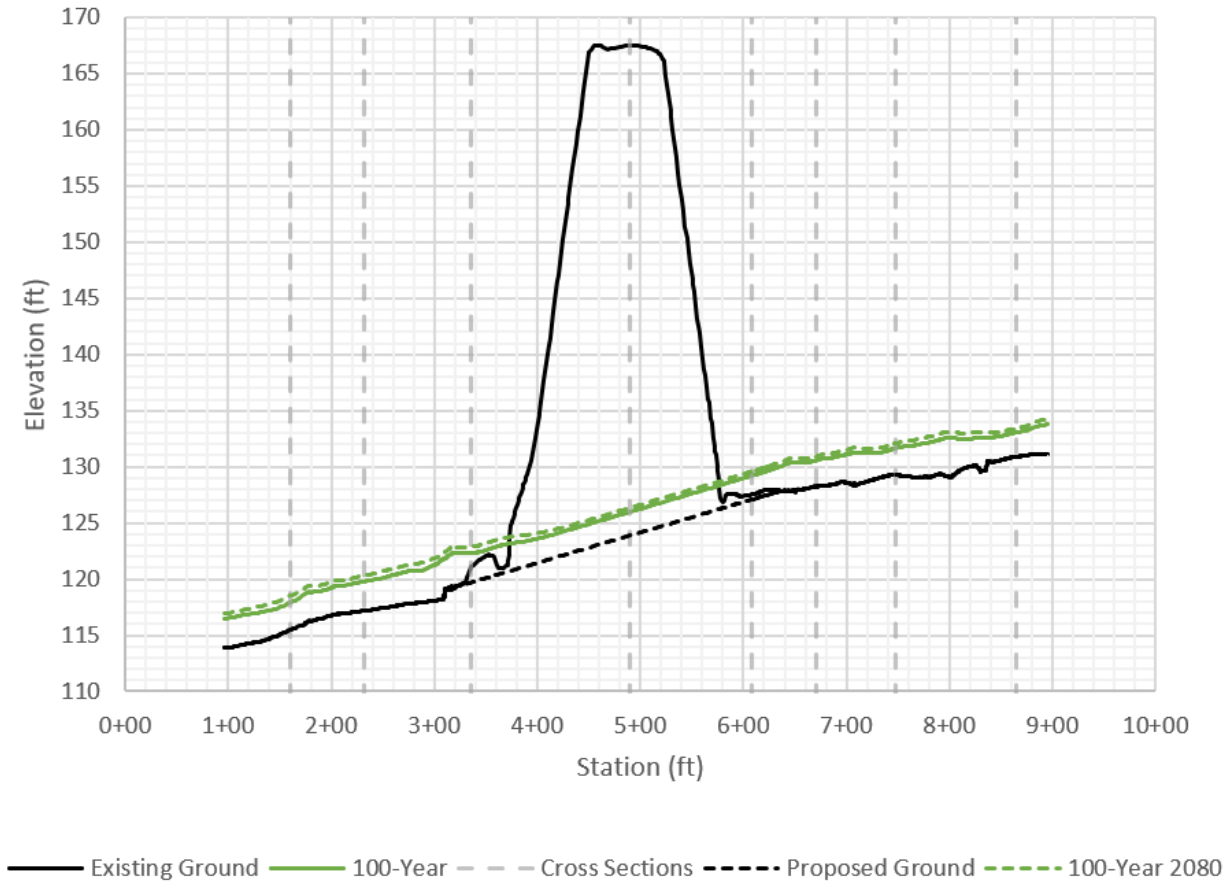


Figure 46: Natural-conditions water surface profiles

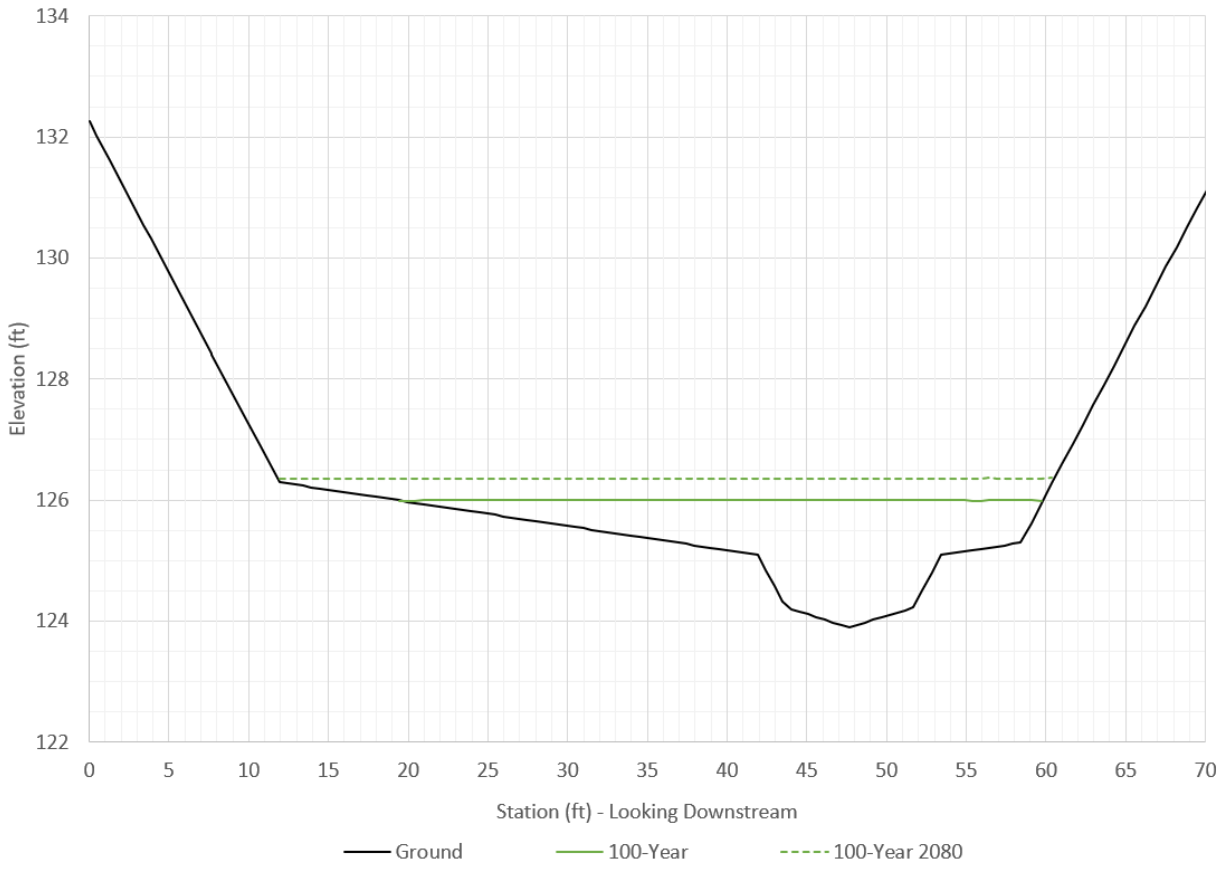


Figure 47: Typical natural conditions cross section (STA 4+90)

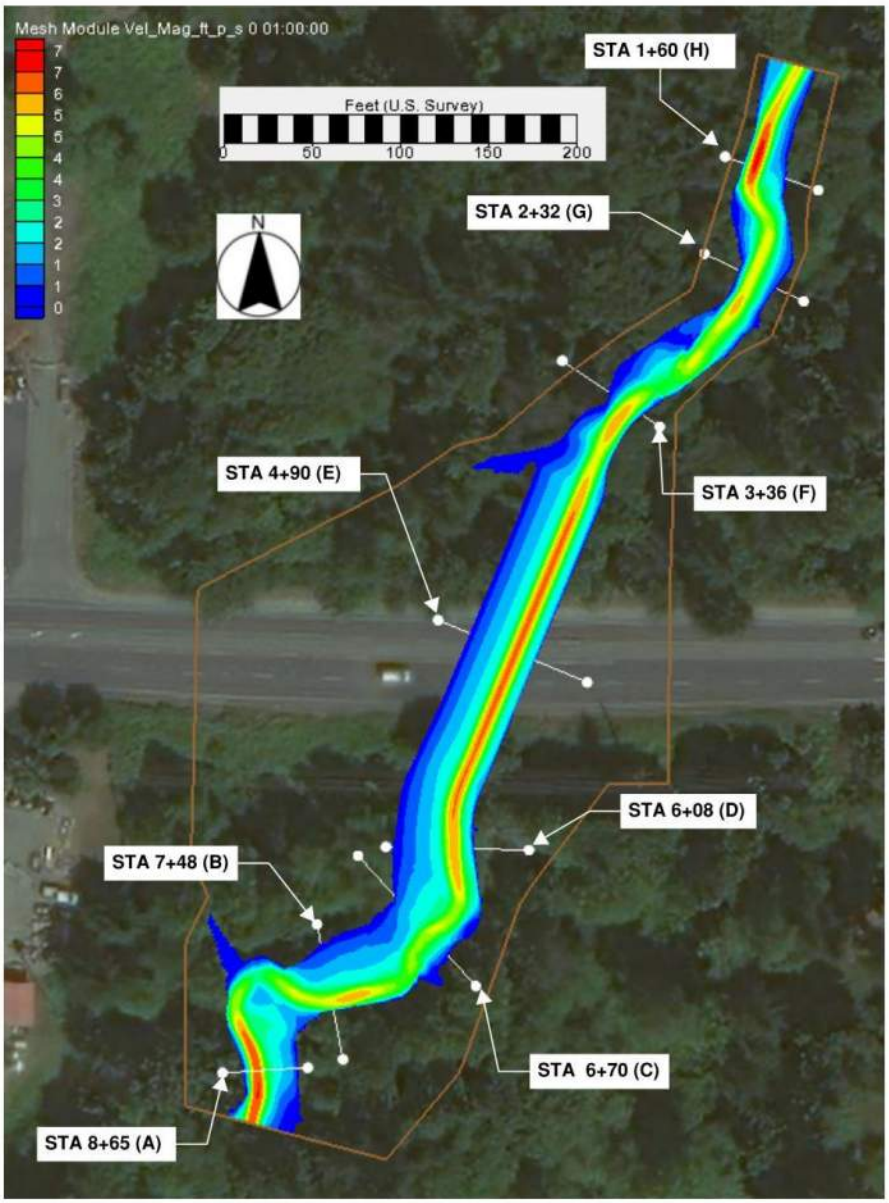


Figure 48: Natural-conditions 100-year velocity map with cross-section locations

Table 10: Natural-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 1+60 (H)	2.18	5.40	1.63
DS 2+32 (G)	1.12	4.01	1.09
DS 3+36 (F)	1.46	4.61	1.27
Structure 4+90 (E)	1.38	5.06	2.02
US 6+08 (D)	1.37	5.14	1.94

Cross-section location	Q100 average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]
US 6+70 (C)	1.84	4.11	1.52
US 7+48 (B)	1.32	4.34	1.16
US 8+65 (A)	1.67	5.28	1.82

a. Right overbank (ROB)/left overbank (LOB) locations were approximated from inspecting the survey and 2-year top width.

4.4 Channel Design

This section describes the channel design developed for SR 166 MP 4.52 Olney Creek.

4.4.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is determined by dividing the flood-prone width (FPW) by the BFW. A ratio under 3.0 is considered a confined channel, and a ratio above 3.0 is considered an unconfined channel. The FPW was determined from the modeled 100-year event width for proposed conditions outside of proposed grading because of a significant backwater effect under existing conditions. These values were each divided by the design BFW of 13.0 feet to compute the FUR. Table 11 shows each FPW, the calculated FUR, and the average FUR across all cross sections. The average downstream result is a FUR of 2.1, while upstream the average FUR is 3.2; therefore, the downstream channel is confined while the upstream channel is slightly unconfined. The channel is unconfined for a length of approximately 200 feet upstream of the existing culvert before transitioning back to confined.

Table 11: FUR determination

Station	FPW (ft)	FUR
DS 1+60 (H)	26.2	2.0
DS 2+32 (G)	28.4	2.2
Average DS	**27.3**	**2.1**
US 6+70 (C)	53.5	4.1
US 7+48 (B)	38.5	3.0
US 8+65 (A)	34.2	2.6
Average US	**42.1**	**3.2**

4.4.2 Channel Planform and Shape

The WCDG requires that the channel planform and shape mimic natural conditions within a reference reach (Barnard et al. 2013). The cross-sectional shape of the proposed channel was determined by matching the cross-section geometry of the upstream reference reach cross-section geometry (from survey data) to generate a reach that both is constructible and will allow natural processes to happen while still maintaining similar flow characteristics to the reference reach. 2D hydraulic modeling results were also used to inform cross-section geometry to better match the existing-conditions flow characteristics.

Within the proposed channel, the modeled 2-year top width is approximately 19.5 feet, and the 2-year thalweg depth is 1.35 feet. The modeled 2-year top width in the upstream reference reach is approximately 21 feet, and the 2-year thalweg depth is 1.6 feet. The slightly wider top width and deeper thalweg depth were anticipated because of the shallower slope within the reference reach. The proposed 2-year top width exceeds the field-measured BFW of 13.0 feet, which was expected because the existing 2-year top width in the reference reach also exceeds the BFW. The channel is expected to maintain its overall shape but will adjust to form channel features such as low-flow meanders or pools from LWM and other habitat features.

The proposed channel shape includes 12 horizontal (H):1 vertical (V) slopes between the toes and 2H:1V bank slopes to create a channel similar to the observed existing channel shape. The channel is symmetrical and on each side the toe is 4.0 feet wide and the bank is 1.7 feet wide. Above the bank the floodplains will be graded at 25H:1V for 5 feet wide on the right and 30 feet wide on the left. Catch slopes at 2H:1V then tie out to match existing grade (Figure 49). For comparison, a series of existing channel sections and the proposed channel shape are superimposed in Figure 50.

A low-flow channel will be added in later stages of the project that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field.

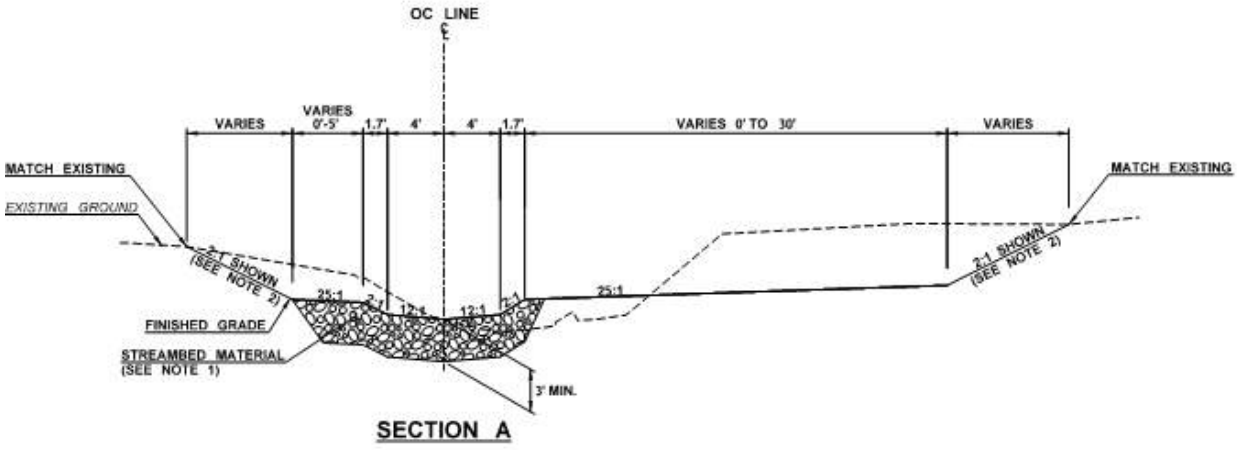


Figure 49: Design cross section (looking upstream)

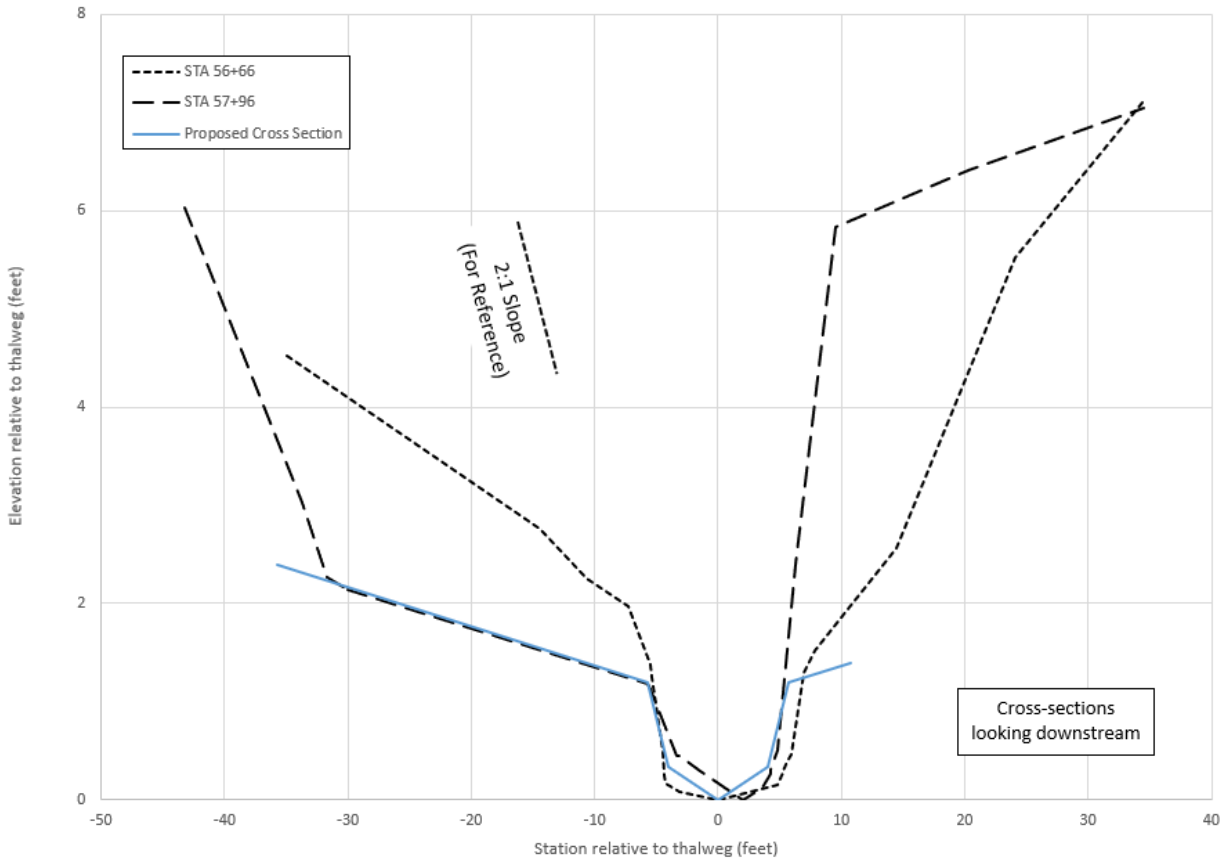


Figure 50: Proposed cross section superimposed with existing survey cross sections

4.4.3 Channel Alignment

The design alignment will be skewed at the crossing to better match the natural topography of the basin and eliminate the sharp bend at the existing culvert outlet. This also eliminates the highly modified, confined section of channel adjacent to the road fill immediately downstream of the culvert as described in Section 2.7.2. The channel will be regraded for approximately 315 feet, including tie-in distance. Upstream the proposed grading will tie into the existing channel approximately 60 feet upstream of the existing culvert inlet. Downstream the proposed grading ties into the existing channel 120 feet downstream of the existing culvert outlet. If the existing channel is filled, approximately 47 LF of potential habitat would be lost as a result of the channel realignment. The preliminary stream design however, leaves the existing channel in place as off channel habitat.

The proposed channel alignment and grading extents are illustrated in design drawings provided in Appendix E. For the preliminary design, a straight alignment was modeled, which provides a conservative estimate of proposed slope and channel velocities for assessment of slope ratio. During future design phases, a meander will be incorporated within the minimum hydraulic opening.

4.4.4 Channel Gradient

The WCDG recommends that the proposed culvert bed gradient be not more than 25 percent steeper (slope ratio less than 1.25) than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 2.7 percent and the average channel gradient from the longitudinal profile is 2.4 percent. This results in a slope ratio of 1.13. The design gradient meets the slope ratio based on the longitudinal profile and best resolves the geologic, geometric, and constructability constraints of the project site. Long-term degradation at the crossing is anticipated based on the longitudinal profile see Section 2.8.4 for a more information.

4.5 Design Methodology

The proposed fish passage design was developed using the 2013 WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2019). Using the guidance in these two documents, the unconfined bridge design method was determined to be the most appropriate at this crossing because the channel is unconfined in the upstream reference reach.

4.6 Future Conditions: Proposed 32-foot Minimum Hydraulic Opening

The hydraulic opening is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified.

The starting point for the design of all WSDOT structures is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. Based on a BFW 13.0 feet, as discussed in Section 2.8.2, the equation calculates a minimum hydraulic opening of 17.6 feet. Further, because of the length of the anticipated structure potentially exceeding 10 times the structure span, the width was increased by 30 percent to allow for meandering. Rounding up to the nearest whole foot results in a minimum hydraulic opening of 23.0 feet based on this methodology. However, velocity ratio was not met with this opening size.

The recommended minimum hydraulic opening was determined through an iterative process, modeling a variety of hydraulic openings from 18 to 32 feet wide and comparing the hydraulic results to the design criteria, specifically velocity ratio. Velocity ratios were calculated by comparing the average proposed channel velocity at the road centerline (STA 4+90) (Figure 45) to the natural condition at the same cross section. This represents a conservative approach to calculating velocity ratio, as the channel has been designed and modeled as straight with no sinuosity. During future design phases, sinuosity will be included in the design, which will likely result in increased channel length, decreased channel slope and lower channel velocities and ultimately a lower velocity ratio. Results of the iteration on hydraulic opening are summarized in Table 12. As the proposed structure size increased, channel velocities and velocity ratios decreased. A proposed run without a structure (48 foot floodplain) was also included to demonstrate the channel velocity increase strictly due to reducing the floodplain roughness from 0.100 to 0.055. Specifying a smoother roughness of 0.055 underneath the structure results in an increase in average channel velocity of 1.3 ft/sec. A 24-foot-wide structure would meet the velocity ratio for the 100-year event, but not the projected 2080 100-year event. Increasing the span to

a 32-foot-wide structure would provide a 1.15 velocity ratio for the projected 2080 100-year flow event. The velocity ratio for the 32-foot-wide structure is met at the projected 2080 100-year flow event when comparing the structure velocity (4+90) to representative cross sections 1+60 and 8+65, which were 1.11 and 1.07, respectively. The cross section at 1+60 is within the downstream reference reach and cross section at 8+65 is located just upstream of the reference reach at a location with a similar slope to the design slope. The 32-foot-wide structure size was moved forward with in the design after discussions with Headquarters Hydraulics. Further discussion is provided in Section 4.7.2.

Table 12: Velocity ratio summary for structures varying from 18 to 32 feet

Iterations	100-year average channel velocities			Projected 2080 100-year average channel velocities		
Structure size (ft)	**Natural-conditions velocity (ft/s)**	**Proposed-conditions velocity (ft/s)**	**Velocity ratio**	**Natural-conditions velocity (ft/s)**	**Proposed-conditions velocity (ft/s)**	**Velocity ratio**
18	5.06	5.94	1.17	5.55	6.84	1.23
24		5.78	1.14		6.55	1.18
26		-	-		6.50	1.17
28		-	-		6.46	1.16
32		5.72	1.13		6.41	1.15
No structure (48)		-	-		6.38	1.15

Velocity ratio = $V_{structure}/V_{natural.}$

In differences between the existing and proposed conditions, the greatest change occurs just upstream of the culvert because the backwater from the existing culvert is removed. Under proposed conditions, the enlarged structure removes the backwater upstream of the culvert. WSEL drops by as much as 4 feet from existing to proposed conditions at the culvert inlet. Shear stress is generally higher in the upstream reach because the existing culvert backwater effect is eliminated. In the downstream reach, shear stress is relatively similar between the existing and proposed conditions, though higher for the projected 2080 100-year flows. Proposed-conditions main channel hydraulic results are summarized for the upstream and downstream cross sections in Table 13. Refer to Figure 51 for cross-section locations and Figure 45 for the alignment used for reporting proposed results. The longitudinal profile is shown in Figure 52, and a typical section through the structure is depicted in Figure 53. Proposed-conditions 100-year velocities are depicted in Figure 54. Figure 55 shows the same velocity map with 2080 predicted 100-year velocities. Average floodplain and main channel velocities are summarized in Table 14.

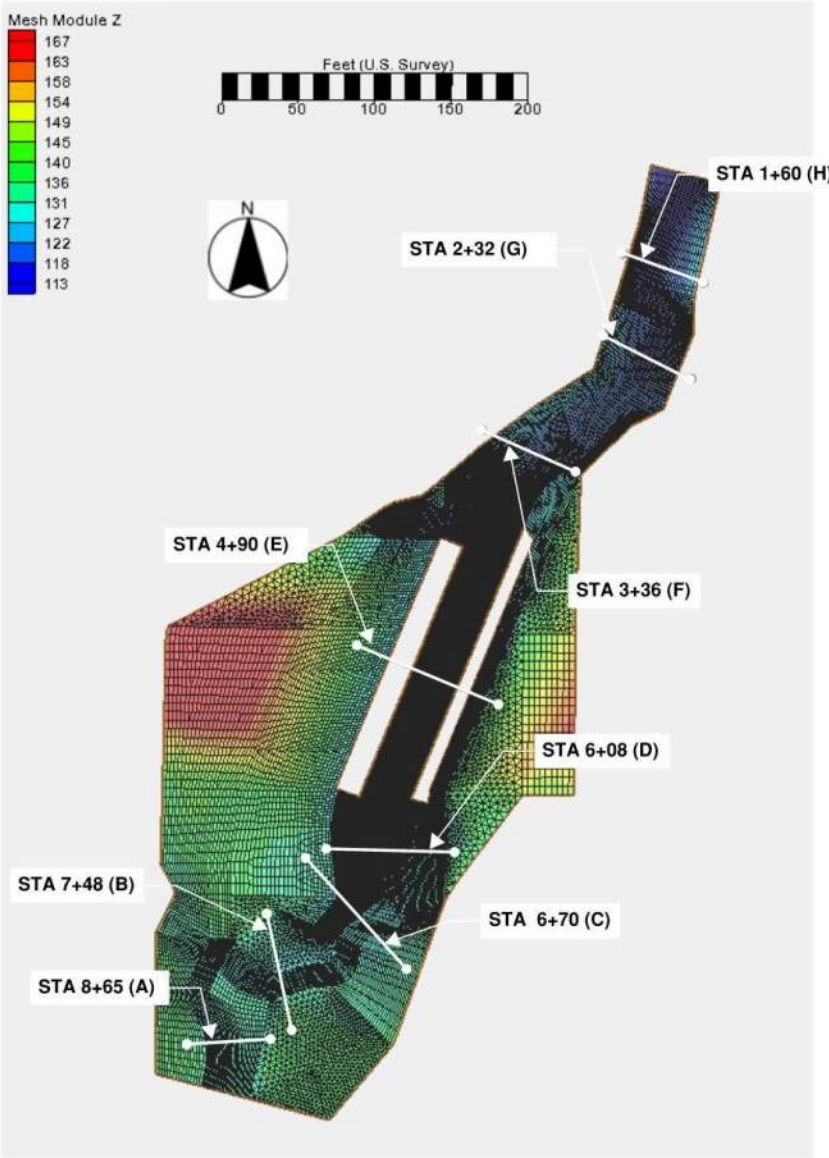


Figure 51: Locations of cross sections on proposed alignment used for results reporting

Table 13: Average main channel hydraulic results for proposed condition

Hydraulic parameter	Cross section	2-year	100-year	2080 predicted 100-year	500-year
Average WSEL (ft)	DS 1+60 (H)	116.89	117.87	118.46	118.14
	DS 2+32 (G)	118.92	119.81	120.32	120.05
	DS 3+36 (F)	121.34	122.31	122.87	122.56
	Structure 4+90 (E)	125.25	125.81	126.12	125.95
	US 6+08 (D)	128.55	129.20	129.57	129.37
	US 6+70 (C)	129.85	130.54	130.90	130.71
	US 7+48 (B)	130.86	131.64	132.06	131.84
	US 8+65 (A)	132.42	133.09	133.46	133.26
Max depth (ft)	DS 1+60 (H)	1.44	2.43	3.03	2.71
	DS 2+32 (G)	1.74	2.63	3.13	2.86
	DS 3+36 (F)	1.63	2.61	3.17	2.86
	Structure 4+90 (E)	1.36	1.92	2.22	2.06
	US 6+08 (D)	1.46	2.12	2.49	2.29
	US 6+70 (C)	1.63	2.33	2.69	2.49
	US 7+48 (B)	1.62	2.40	2.82	2.60
	US 8+65 (A)	1.52	2.17	2.53	2.34
Average velocity (ft/s)	DS 1+60 (H)	4.34	5.39	5.75	5.57
	DS 2+32 (G)	2.70	4.01	4.72	4.34
	DS 3+36 (F)	3.40	4.62	5.22	4.92
	Structure 4+90 (E)	4.27	5.72	6.41	6.05
	US 6+08 (D)	4.11	5.15	5.57	5.35
	US 6+70 (C)	3.32	4.11	4.52	4.31
	US 7+48 (B)	3.24	4.34	4.79	4.55
	US 8+65 (A)	3.98	5.28	6.00	5.62
Average shear (lb/SF)	DS 1+60 (H)	2.31	3.32	3.69	3.50
	DS 2+32 (G)	1.09	2.28	3.09	2.64
	DS 3+36 (F)	1.24	2.01	2.47	2.24
	Structure 4+90 (E)	1.61	2.44	2.88	2.65
	US 6+08 (D)	1.91	2.65	2.94	2.79
	US 6+70 (C)	0.78	1.17	1.42	1.29
	US 7+48 (B)	0.87	1.56	1.94	1.73
	US 8+65 (A)	1.21	2.09	2.70	2.37

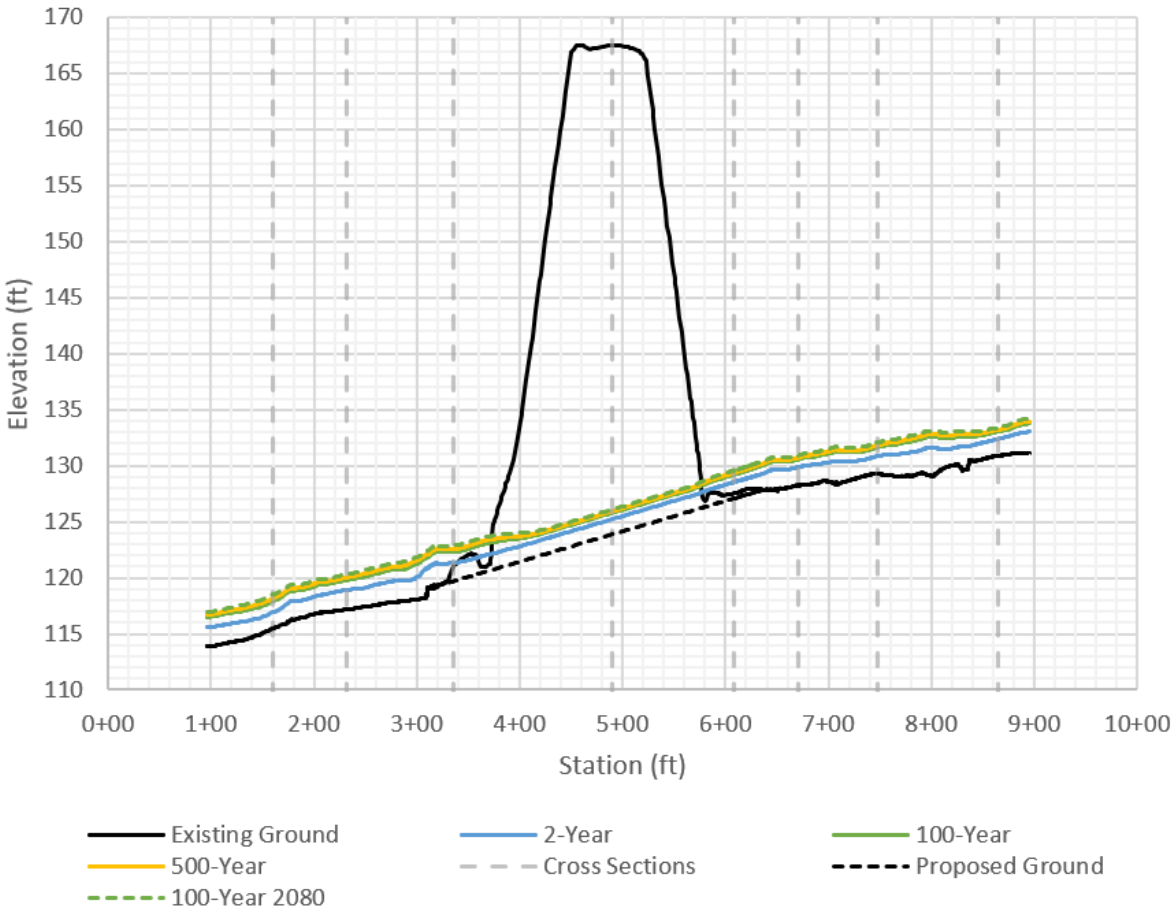


Figure 52: Proposed-conditions water surface profiles

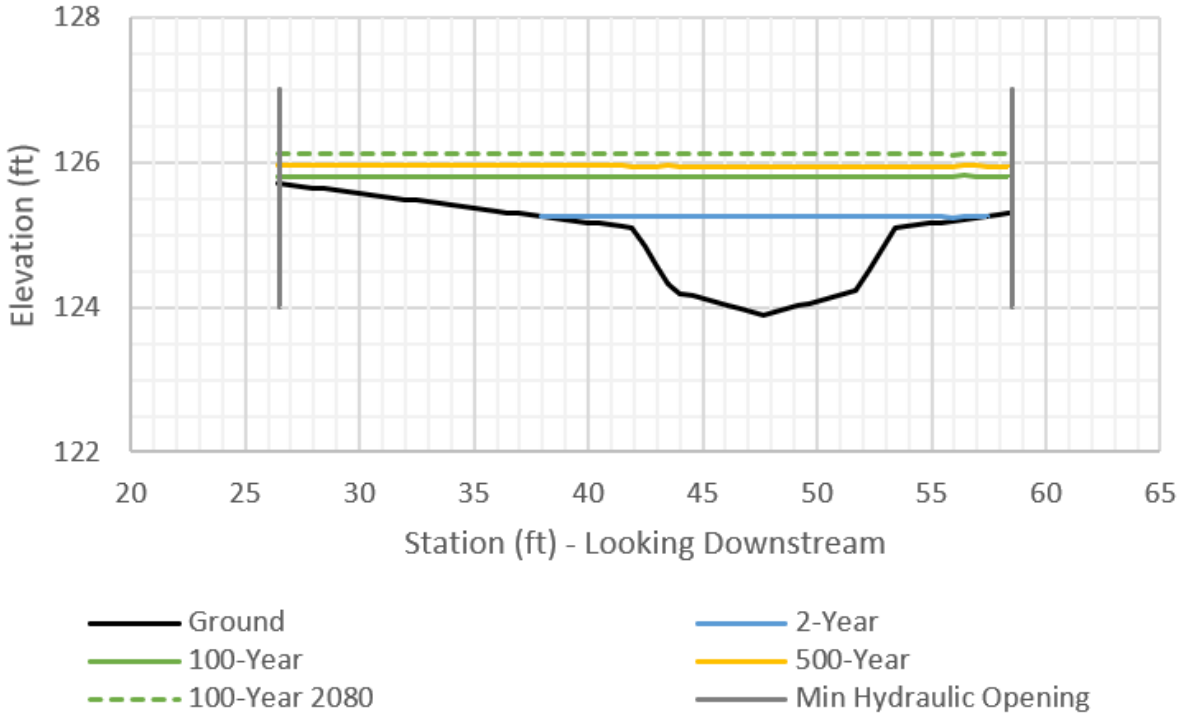


Figure 53: Typical section through proposed structure (STA 4+90)

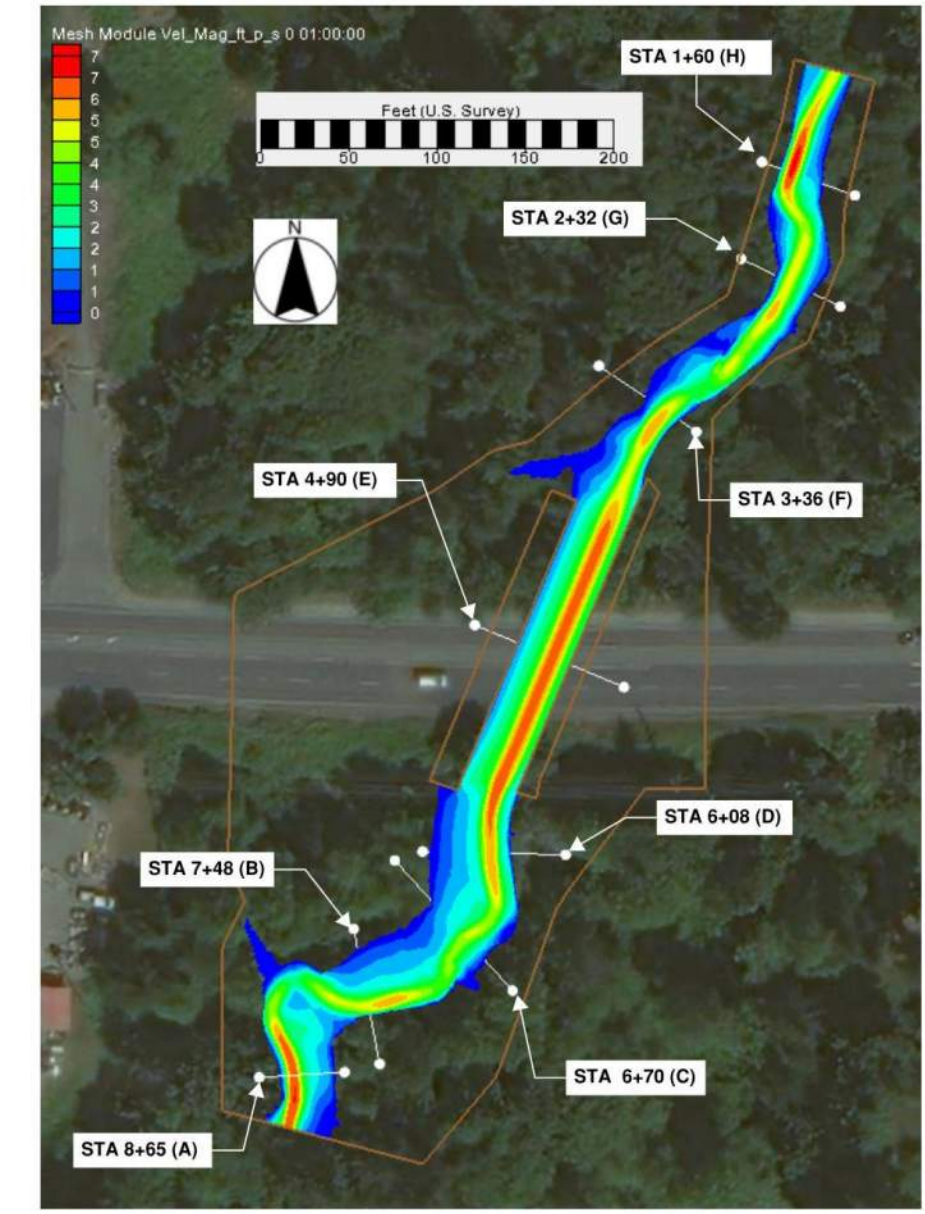


Figure 54: Proposed-conditions 100-year velocity map

Table 14: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 1+60 (H) DS reference reach	2.18	5.39	1.63	2.73	5.75	2.56
DS 2+32 (G)	1.12	4.01	1.09	1.48	4.72	1.65
DS 3+36 (F)	1.46	4.62	1.27	1.68	5.22	2.09
Structure 4+90 (E)	2.42	5.72	3.42	3.59	6.41	4.51
US 6+08 (D)	1.37	5.15	1.94	1.93	5.57	2.81
US 6+70 (C)	1.84	4.11	1.52	2.36	4.52	1.67
US 7+48 (B) US reference reach	1.32	4.34	1.16	2.10	4.79	1.44
US 8+65 (A)	1.67	5.28	1.82	1.58	6.00	2.38

a. Right overbank (ROB)/left overbank (LOB) locations were approximated from inspecting the survey and 2-year top width.

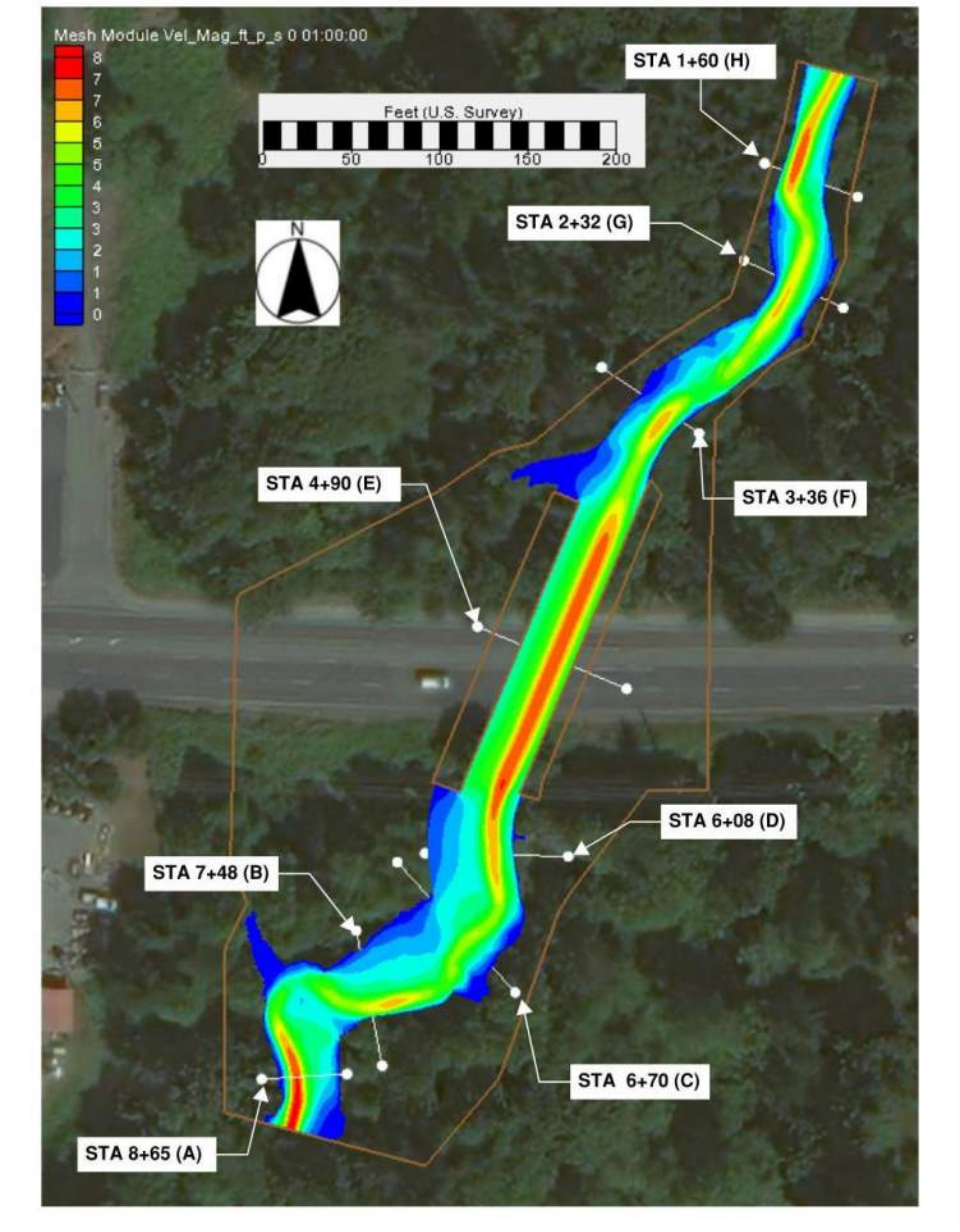


Figure 55: Proposed-conditions 2080 predicted 100-year velocity map

4.7 Water Crossing Design

This section describes the water crossing design developed for SR 166 MP 4.52 Olney Creek.

4.7.1 Structure Type

No structure type has been recommended by Headquarters Hydraulics. The layout and structure type will be determined at later project phases.

4.7.2 Minimum Hydraulic Opening Width and Length

Based on the stream simulation equation and iterative velocity ratio sizing, a minimum hydraulic opening of 32 feet was determined to be necessary to allow for natural processes to occur. The stream simulation equation including the long culvert criteria dictates the minimum hydraulic opening base size of 23 feet, but this was increased because of the velocity ratio. The projected 2080 100-year flow event was evaluated and the main channel velocity comparisons for these flow rates can be seen in Table 15. Further discussion on this is provided in Section 4.6.

Table 15: Channel velocity comparison for 32-foot structure

Location	100-year velocity (ft/s)	2080 predicted 100-year velocity (ft/s)	Difference (ft/s)
Downstream of structure (STA 1+60)	5.39	5.75	0.36
Downstream of structure (STA 2+32)	4.01	4.72	0.71
Downstream of structure (STA 3+36)	4.62	5.22	0.60
Through structure (STA 4+90)	5.72	6.41	0.69
Upstream of structure (STA 6+08)	5.15	5.57	0.42
Upstream of structure (STA 6+70)	4.11	4.52	0.41
Reference reach (STA 7+48)	4.34	4.79	0.45
Upstream of structure (STA 8+65)	5.28	6.00	0.72

A minimum hydraulic opening of 32 feet is recommended. The PHD design currently shows a structure length of approximately 174 feet. This proposed length will likely change with future design considerations and is approximate for this PHD Report.

4.7.3 Freeboard

The WCDG recommends providing sufficient freeboard to prevent excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate, to allow the free passage of debris expected to be encountered, and generally suggests a minimum 2-foot freeboard for streams of this size above the 100-year WSEL (Barnard et al. 2013). Since the minimum hydraulic opening is larger than 20 feet, a minimum freeboard of 3 feet was incorporated into the design. WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSEL and the projected 2080 100-year WSEL. The required freeboard is 3 feet above the 2080 projected 100-year WSEL. This provides a minimum internal clearance of 5.8 feet. Additionally, a recommended freeboard of 6 feet above the top of bank elevation is recommended for maintenance and can be accommodated at this site due to the tall fill embankment present.

Long-term degradation, aggradation, and debris risk were also evaluated at this location. No additional freeboard was added to the structure to account for the risk of aggradation or debris. More information on the risk for long-term degradation and aggradation can be found in 2.8.4.

4.7.3.1 Past Maintenance Records

As discussed previously in Section 2.4, no maintenance records are available for this crossing.

4.7.3.2 Wood and Sediment Supply

There is history and potential for LWM to be recruited throughout the stream reach. LWM present in the channel is embedded in the banks and the forest floor and has historically been recruited naturally from the banks. The basin is largely developed already, though new development could take place. It is assumed that any new development would not result in significant sediment input to the channel because of modern surface water regulations. LWM transport through the reach is not likely a significant concern because of the size of the reach relative to likely LWM inputs.

4.7.3.3 Flooding

The project is within a regulatory special flood hazard area (Section 2.3) but the roadway does not overtop for any modeled flow events. The proposed project will reduce upstream flooding extents.

4.7.3.4 Future Corridor Plans

There are currently no long-term plans to improve SR 166 through this corridor.

5 Streambed Design

This section describes the streambed design developed for SR 166 MP 4.52 Olney Creek.

5.1 Bed Material

The proposed bed material gradation was created using standard WSDOT specification material to mimic the gradation documented in the pebble count as closely as possible. The proposed mix will consist of 100 percent streambed sediment because the reference reach was made up of sands and gravels and very few cobbles. The streambed substrate is the smallest material able to be specified so the design is not able to match the observed D50 within the 20 percent goal. A comparison of the observed and proposed streambed material size distribution is provided in Table 16.

Table 16: Comparison of observed and proposed streambed material

Sediment size	Observed diameter (in)	Proposed diameter (in)
$\mathbf{D_{16}}$	0.3	0.02
$\mathbf{D_{50}}$	0.5	0.8
$\mathbf{D_{84}}$	0.9	2.1
$\mathbf{D_{95}}$	1.4	2.4
$\mathbf{D_{100}}$	3.0	2.5

The Modified Critical Shear Stress Approach (as described in Appendix E of the United States Forest Service [USFS] Guidelines) was used to analyze mobility for the proposed streambed material at the project site (USFS 2008). The sediment mobility analysis indicates that all material sizes are anticipated to move at the 2-year flow and higher. At the time of the site visit, sediment supply within the system appeared to be healthy. Because of this healthy sediment supply and the size similarity between observed and proposed materials, mobility of this

material is not a concern as material that is mobilized will be replaced from upstream. See Appendix D for streambed material sizing and sediment mobility calculations.

5.2 Channel Complexity

The proposed channel is designed to mimic existing conditions as much as possible by following natural bends and disturbing only the area necessary to adequately tie into the existing ground. To promote channel complexity LWM will be placed to offer channel-forming features, bank stability, and complexity to enhance fish habitat. The LWM installations will provide structures conducive to creating stream complexity and facilitate geomorphic functions in segments that will have low natural LWM delivery rates while new and impacted riparian areas recover from construction activities related to installation of the new crossings and regrading of the stream channel. LWM is not currently proposed within the minimum hydraulic opening.

LWM, in conjunction with bank-side bioengineering, will also help protect newly constructed banks and will promote long-term bed stability by creating pools, sinuosity, hard points, and channel roughness. Bank-side bioengineering is recommended immediately after construction for bank stability and will require further coordination with the landscape architect during future phases of design.

5.2.1 Design Concept

To promote stream complexity and restore natural function WSDOT uses the Fox and Bolton (2007) 75th percentile for wood loading targets. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading because of development. The 75th percentile targets based on 313 feet of stream length are 10 key pieces, 36 total LWM pieces, and 123.6 cubic yards of LWM. A conceptual LWM layout developed for this project area assuming a culvert is provided in Figure 56 and assuming a bridge or buried structure in Figure 57. LWM will be placed outside the structure but within the grading extents. The conceptual layout assuming a culvert proposes 19 key pieces, 36 total pieces, and 74.6 cubic yards of LWM. If the proposed structure is a bridge, additional channel length will be available to install LWM. The proposed LWM for a bridge includes 25 key pieces, 44 total pieces, and 97.0 cubic yards of LWM. The volume target will not be met for either configuration because of the length of the crossing relative to the amount of grading outside the crossing. The LWM layouts are conceptual; further coordination will be needed with review agencies for the detailed design of habitat structures as design progresses.

LWM structures placed in the stream serve as habitat features for fish. The LWM layout for the proposed channel provides habitat complexity, flow refuge, and pools that allow fish to rest, feed, and protect themselves, especially during high flows. Preformed pools are recommended at rootwads interacting with flow. Risk for fish stranding during summer flow conditions is minimal because proposed grading directs flow back to the main channel and does not promote standing pools. Additionally, a low-flow channel will be constructed and directed in the field by the engineer to help minimize stranding during low flows by providing connectivity between the habitat complexity features. At this time, anchoring and mobility for LWM is not determined and will be assessed for the Final Hydraulic Design (FHD). Within the structure, partial spanning meander bars will be used to promote channel complexity, prevent entrainment of flow along the

proposed structure wall, and will have similar function to the natural features observed in the reference reach.

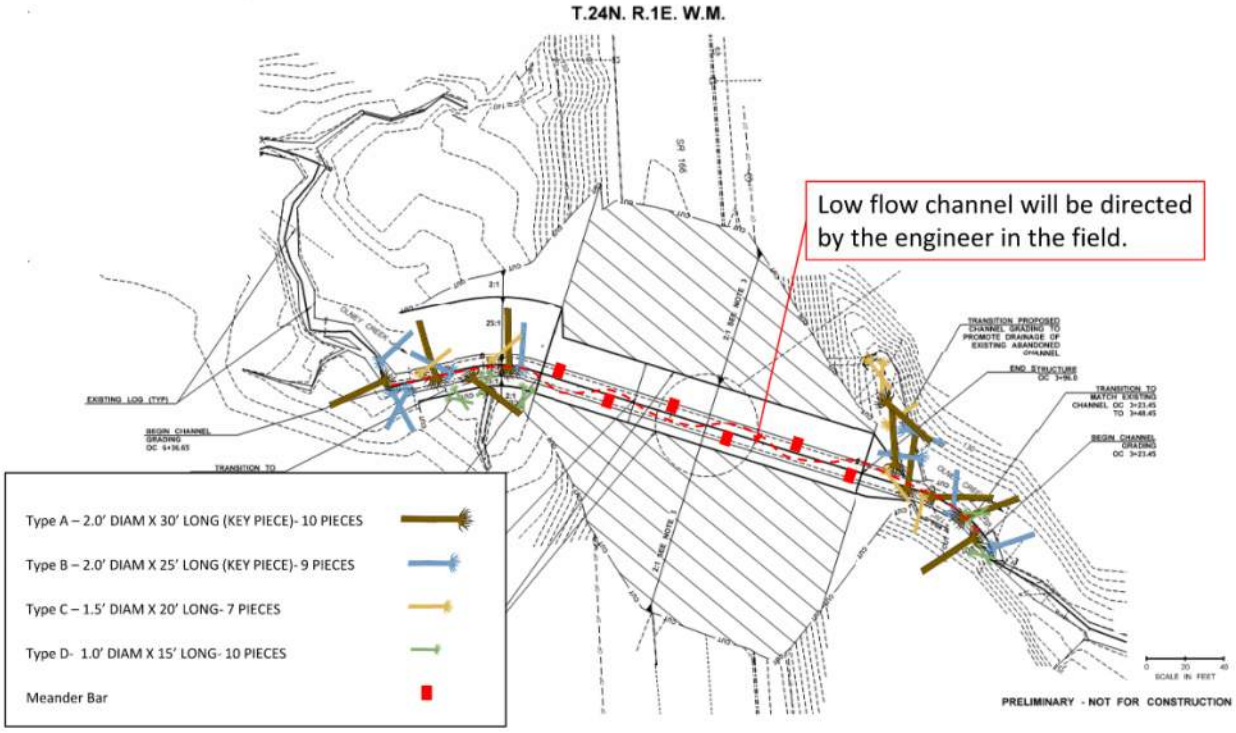


Figure 56: Conceptual layout of habitat complexity features assuming culvert

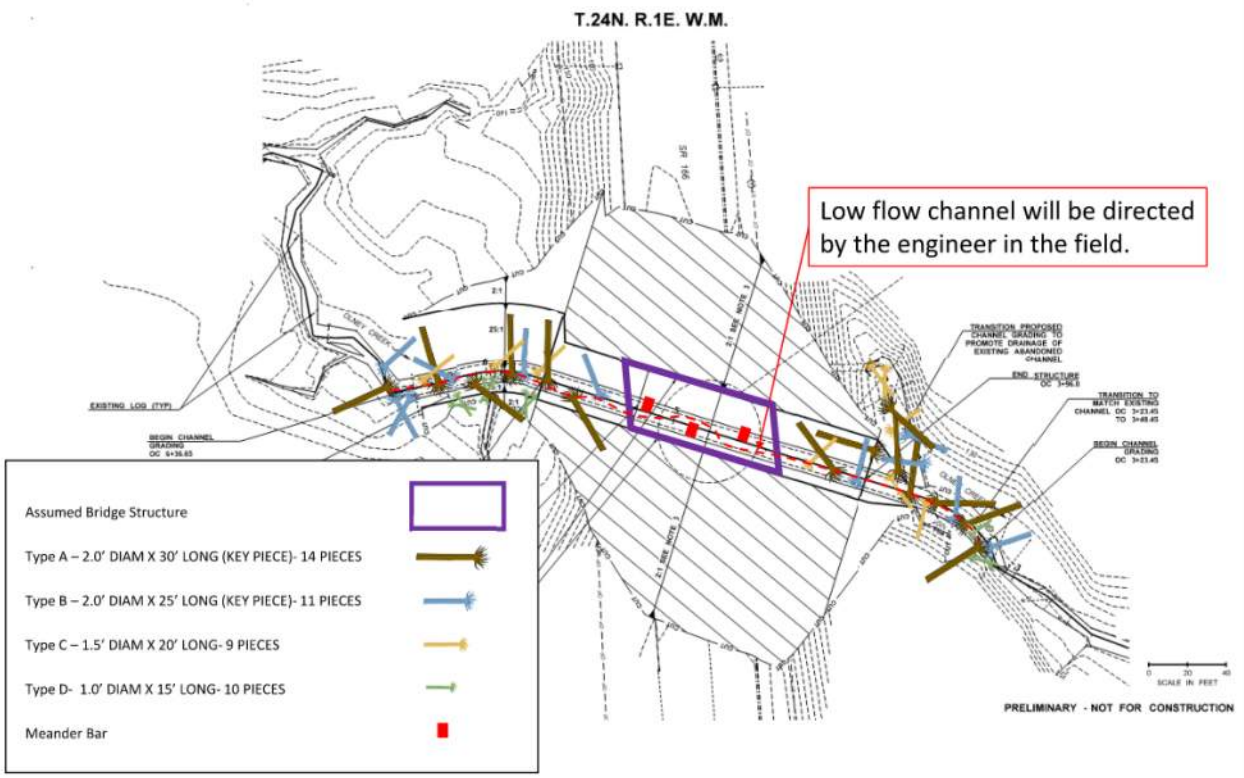


Figure 57: Conceptual layout of habitat complexity features assuming bridge or buried structure

6 Floodplain Changes

This project is within a mapped floodplain. The pre-project and expected post-project conditions were evaluated to determine whether there would be a change in WSEL and floodplain storage. A Flood Risk Assessment technical memorandum will be produced for this crossing at a later date.

6.1 Floodplain Storage

Floodplain storage may be impacted by the proposed structure. Installation of a larger hydraulic opening will reduce the amount of backwater and associated peak flow attenuation that was being provided by the smaller existing culvert. A comparison of pre- and post-project peak flow events was not quantified as the models were run with a steady flow rate specified at the upstream boundary of the model.

6.2 Water Surface Elevations

Installation of the proposed structure would eliminate the backwater impacts immediately upstream of the existing culvert, resulting in a reduction in WSEL upstream. The WSEL is reduced by as much as 4 feet near the inlet of the existing culvert at the 100-year event as shown in Figure 58. Figure 59 also depicts the extent of backwater that is eliminated. Increases in proposed WSEL compared to existing conditions were minor and limited to small localized area at

the outlet of the proposed culvert, with a maximum increase of WSEL of approximately 0.2 foot. Properties surrounding the crossing are much higher in elevation than both the existing and proposed flood elevations.

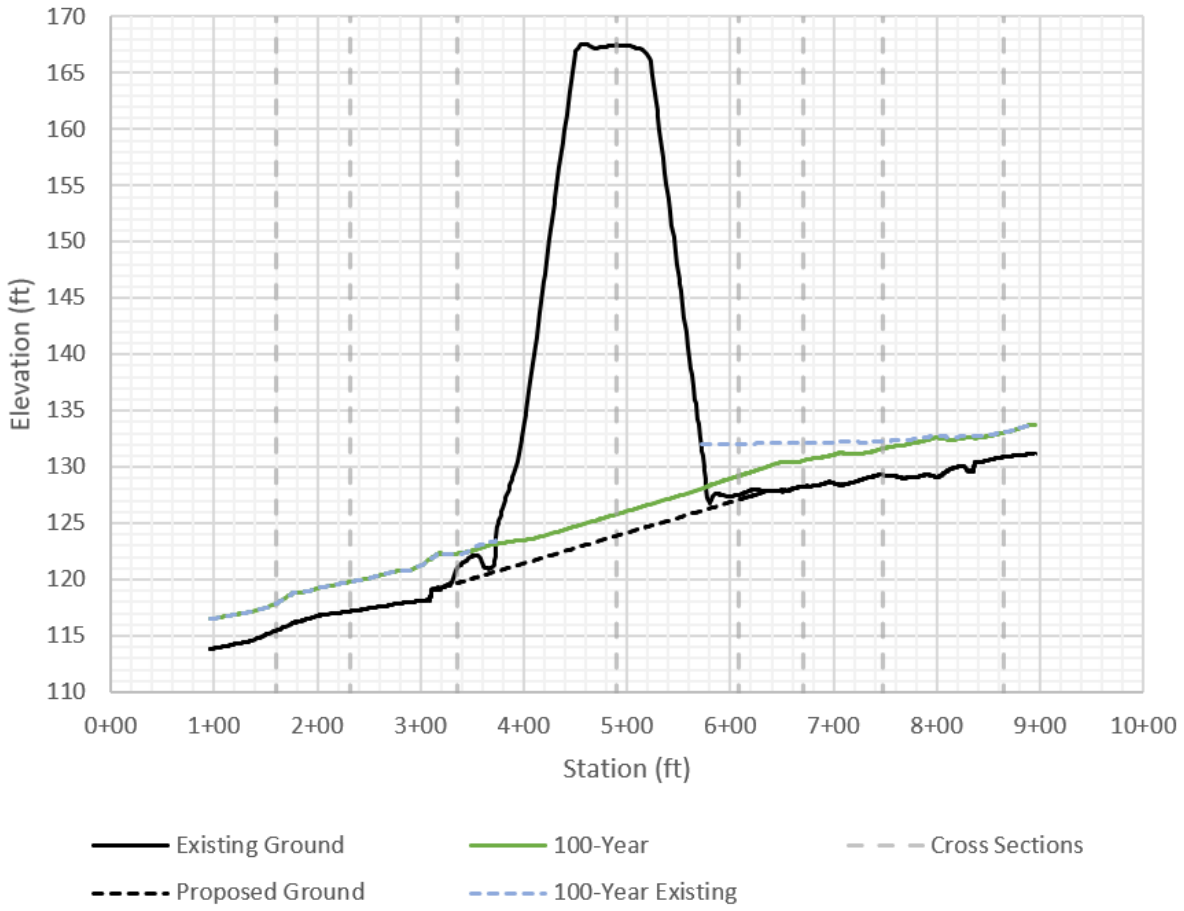


Figure 58: Existing and proposed 100-year water surface profile comparison

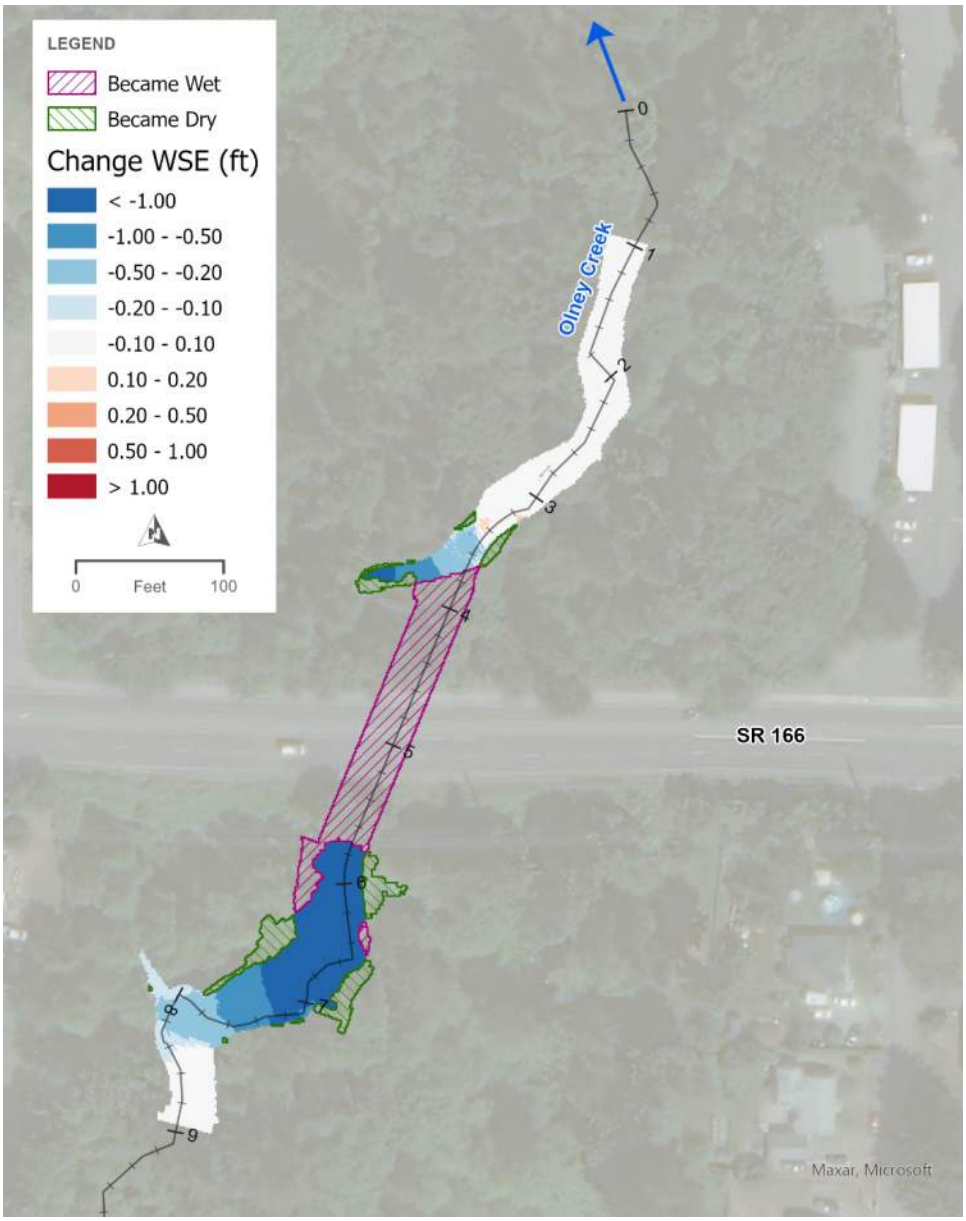


Figure 59: 100-year water surface elevation change from existing to proposed conditions

Values within Figure 59 indicate the feet of rise or fall in WSEL from existing to proposed conditions. Purple and green hatching represent new water surface extents and water surface extents that are no longer wet, respectively, under proposed conditions.

7 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. For bridges and buried structures, the largest risk to these structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passability for all expected life stages and species in a system.

7.1 Tools

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the 2080 percent increase throughout the design of the structure. Appendix E contains the information received from WDFW for this site.

7.2 Hydrology

WSDOT uses the best available science for assessing site hydrology for each design. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is reevaluated to determine whether adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 predicted 100-year flow event to check for climate resilience. The design flow for the crossing is 134 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 51.4 percent, yielding a projected 2080 flow rate of 203 cfs.

7.3 Summary

A minimum hydraulic opening of 32 feet and a minimum freeboard of 3 feet above the 100-year 2080 WSEL allows for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2080 100-year flow event. This will provide a robust structure design that is resilient to climate change and allows the system to function naturally, including the passage of sediment, debris, and water in the future.

8 Scour Analysis

Total scour will be computed during later phases of the project using the 100-year, 500-year, and projected 2080 100-year flow events. The structure will be designed to account for the potential scour at the projected 2080 100-year flow events. For this phase of the project, the risk for lateral migration and potential for degradation are evaluated on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case.

8.1 Lateral Migration

In the upstream reach the risk of lateral migration is moderate. Due to the shallower profile slope and unconfined planform, it may migrate within the valley walls. The risk of channel migration within the structure is also moderate due to lack of vegetation and low bank floodplain. Countermeasures to address lateral migration risk to the structure will be evaluated in the FHD.

8.2 Long-term Aggradation/Degradation of the Channel Bed

Long-term degradation potential was visually estimated to be approximately 5 feet at the proposed structure inlet based on projecting the prevailing slope of 2.4 percent upstream through the crossing, as shown in Figure 60. See Section 2.8.4 for more information on the longitudinal profile. Localized sedimentation may occur because of the large amount of LWM and natural channel processes, but based on site observations is not expected to be significant.

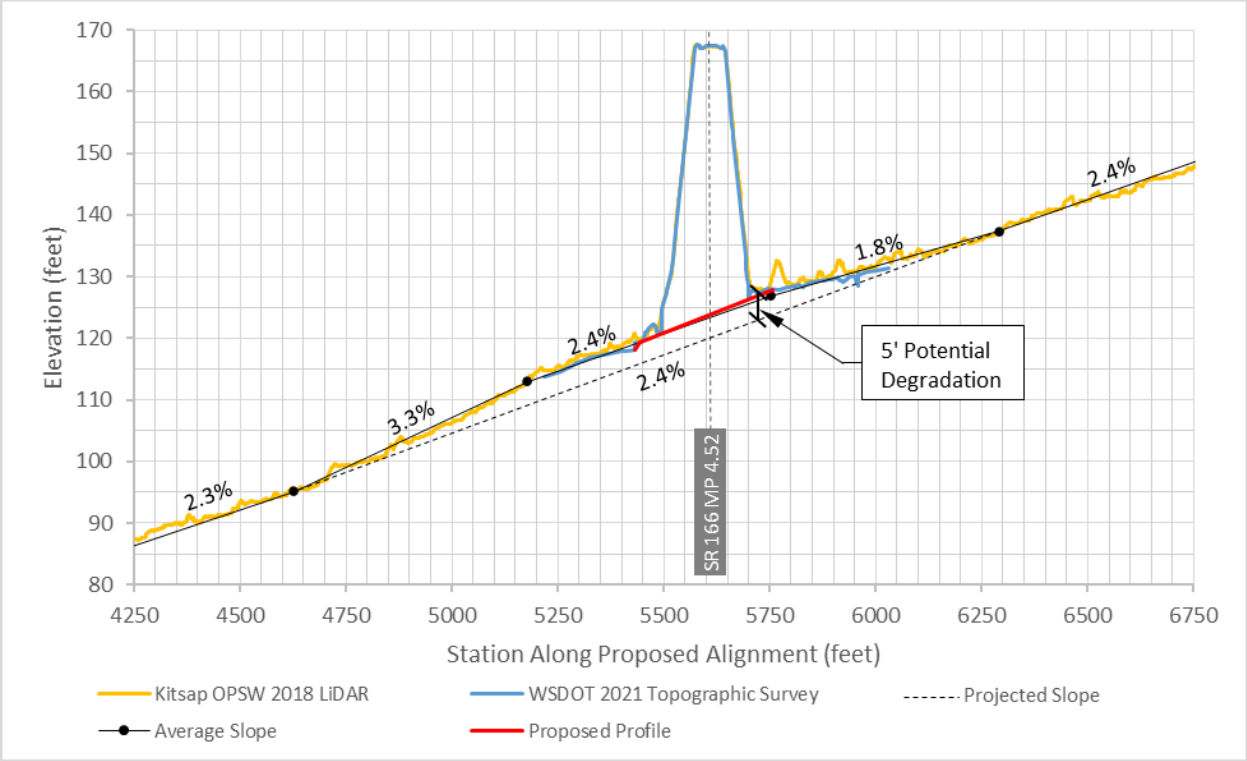


Figure 60: Potential long-term degradation at the proposed structure upstream face

Summary

Table 17 presents a summary of the results of this PHD Report.

Table 17: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	8,255 LF	2.4 Site Description
Bankfull width	Reference reach found?	Yes	2.8.1 Reference Reach Selection
	Design BFW	13.2	2.8.2 Channel Geometry
	Concurrence BFW	Not yet	2.8.2 Channel Geometry
Channel slope/gradient	Existing crossing	0.024	2.8.4 Vertical Channel Stability
	Reference reach	0.024	2.8.1 Reference Reach Selection
	Proposed	0.027	4.4.4 Channel Gradient

Countersink	Proposed	See links	4.7.3 Freeboard / 8 Scour Analysis
	Added for climate resilience	See links	4.7.3 Freeboard / 8 Scour Analysis
Scour	Analysis	TBD	8 Scour Analysis
	Streambank protection/stabilization	TBD	8 Scour Analysis
Channel geometry	Existing	See link	2.8.2 Channel Geometry
	Proposed	See link	4.4.2 Channel Planform and Shape
Channel conditions	Dry channel in summer	No	2.7.2 Existing Conditions
Floodplain continuity	FEMA mapped floodplain	Yes	2.3 Floodplains
	Lateral migration	Low	2.8.5 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Changes
Freeboard	Required above 100 yr	3.0	4.7.3 Freeboard
	Added for climate change resilience	0.4	4.7.3 Freeboard
	Additional recommended	0.0	4.7.3 Freeboard
Maintenance clearance	Proposed	5.8	4.7.3 Freeboard
Substrate	Existing	See link	2.8.3 Sediment
	Proposed	See link	5.1 Bed Material
	Coarser than existing?	Yes	5.1 Bed Material
Hydraulic opening	Proposed	32 ft	4.7.2 Minimum Hydraulic Opening Width and Length
	Added for climate change resilience	Yes	4.7.2 Minimum Hydraulic Opening Width and Length
Channel complexity	LWM for bank stability	No	5.2 Channel Complexity
	LWM for habitat	Yes	5.2 Channel Complexity
	Meander bars	Yes	5.2 Channel Complexity
	Boulder clusters	No	5.2 Channel Complexity
	Coarse bands	No	5.2 Channel Complexity
	Mobile wood	TBD	5.2 Channel Complexity
Crossing length	Existing	169 ft	2.7.2 Existing Conditions
	Proposed	174 ft	4.7.2 Minimum Hydraulic Opening Width and Length
Floodplain utilization ratio (FUR)	Flood-prone width	US 42.1 ft DS 27.3 ft	4.4.1 Floodplain Utilization Ratio
	Average FUR upstream and downstream	US 3.2 DS 2.1	4.4.1 Floodplain Utilization Ratio
Hydrology/design flows	Existing	See link	3 Hydrology and Peak Flow Estimates
	Climate change resilience	See link	3 Hydrology and Peak Flow Estimates
Channel morphology	Pool riffle	See link	2.8.2 Channel Geometry
	Pool riffle	See link	5.2 Channel Complexity
Channel degradation	Potential	5 ft	8.2 Long-term Aggradation/Degradation of the Channel Bed
	Allowed?	Yes	8.2 Long-term Aggradation/Degradation of the Channel Bed
Structure type	Recommendation	No	4.7.1 Structure Type
	Type	TBD	4.7.1 Structure Type

References

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: SRH-2D Model Results

Appendix D: Streambed Material Sizing Calculations

Appendix E: Stream Plan Sheets, Profile, Details

Appendix F: Scour Calculations

Appendix G: Manning's Calculations

Appendix H: Large Woody Material Calculations

Appendix I: Future Projections for Climate-Adapted Culvert Design

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

122°37'14"W 47°32'15"N

122°36'37"W 47°31'50"N

Feet 1:6,000

0 250 500 1,000 1,500 2,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 Cross Sections with 1% Annual Chance
- 17.5 Water Surface Elevation
- Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 8/9/2021 at 11:56 AM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12463
	Project Name: Olympic Region Fish Passage – 16 PHDs	Date: 04/05/21
	Project Office: Pre-Design Team to Tumwater Design PEO	Time of Arrival: 04/05/21 - 9:30 AM 09/22/21 - 2:00 PM
	Stream Name: Olney Creek (Karcher Creek)	Time of Departure: 04/05/21 - 12:30 PM 09/22/21 - 4:00 PM
WDFW ID Number: 15.0201 0.90	Tributary to: Sinclair Inlet	Weather: 04/05/21 - Sunny, mid-50s 09/22/21 - Cloudy, mid-60s
State Route/MP: SR166 MP4.52	Township/Range/Section/ ¼ Section: T24N/R01E/36, T24N/R01E/25	Prepared By: Jeff Price
County: Kitsap	Purpose of Site Visit: Field Reconnaissance	WRIA: 15

Meeting Location:
SR 166 MP 4.52 Olney Creek (WDFW 15.0201 0.90)

Attendance List:

Name	Organization	Date	Role
Shaun Bevan	HDR	04/05/21, 09/22/21	HDR Senior Water Resources Engineer
Ian Welch	HDR	04/05/21	HDR Fisheries Biologist
Kristin LaForge	HDR	04/05/21	HDR Water Resources EIT
Jeff Price	HDR	04/05/21	HDR Water Resources Engineer
Kate Fauver	WSDOT	09/22/21	WSDOT Senior Transportation Planner
Cade Roler	WSDOT	09/22/21	WSDOT Tribal Liaison
Nazmul Alam	WSDOT	09/22/21	WSDOT
Alison O'Sullivan	Suquamish Tribe	09/22/21	Suquamish Tribal Representative
Damon Ramero	WSDOT	09/22/21	WSDOT Fish Passage Coordinator
Carl Ward	WSDOT	09/22/21	WSDOT Environmental
Dave Molenaar	WSDOT	09/22/21	WSDOT Biology Program Manager
Dave Collins	WDFW	09/22/21	WDFW Habitat Biologist
Pad Smith	WDFW	09/22/21	WDFW Habitat Engineer

Bankfull Width:

Describe measurements, locations, known history, summarize on site discussion

HDR conducted an independent site visit on April 5, 2021 to measure bankfull width (BFW), collect pebble count data, and locate a reference reach. HDR walked the stream approximately 400 feet upstream and approximately 350 feet downstream of the existing 4 foot by 4 foot concrete box culvert crossing. HDR collected four bankfull width measurements, two upstream of the crossing and two downstream. See Figure 1 for measurement locations.

A second site visit with HDR, WSDOT, WDFW and the Suquamish Tribe was conducted to gain concurrence on bankfull width measurements and other design considerations on September 22, 2021. An additional bankfull width measurement was taken during the second site visit downstream of the crossing as well as one slight revision to a previously measured bankfull width. Bankfull measurements are summarized in Table 1. The measured bankfull widths resulted in a **design average bankfull width of 13.2 feet.**

See the last page of this field report for further notes on discussions of concurrence and decisions made that help to inform the design.

Table 1: Bankfull width measurements

BFW #		Width (ft)	Included in Design Average	Concurrence Notes
Regression Eqn		11.8	No	
US	1	13.0	Yes	No revisions
	2	14.5	Yes	No revisions
DS	3	13.5	Yes	Increased slightly
	4	11.25	Yes	No revisions
	5	13.5	Yes	New measurement
Design Average		**13.2**	-	

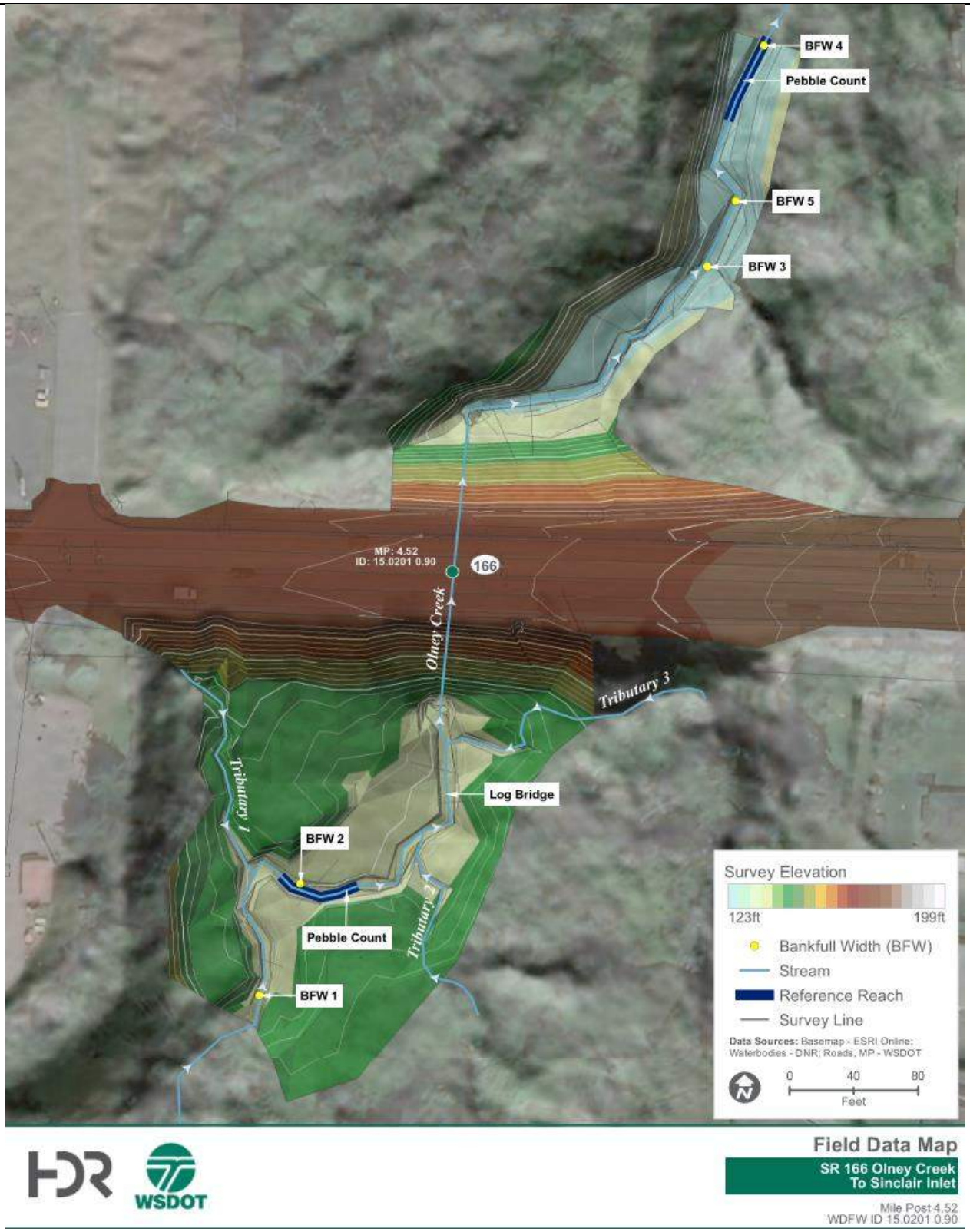


Figure 1: Reference reach, bankfull width, and pebble count locations

Reference Reach:

Describe location, known history, summarize on site discussion, appropriateness, bankfull measurement

Two reference reaches were identified during the site visit, one upstream of the crossing and one downstream. Material size within each reference reach was similar and detailed results are presented below. The slope within the upstream reference reach was approximately 1-1.5 percent and the slope in the downstream reference reach was slightly steeper at approximately 2 percent, as measured from survey data.

An upstream reference reach was identified approximately 180 feet upstream of the culvert inlet (Figure 1). The reference reach is located sufficiently upstream of the existing crossing and any associated backwater influences. Bankfull width (BFW) measurement 2 was taken within the reference reach in a relatively straight section of channel outside of backwater influence of the culvert and outside of the influence of LWM (large woody material) present in the reach. Cross section geometry in the reference reach will be used to inform channel design. Site conditions of the reference reach where the bankfull width measurement was taken can be viewed in Figure 5.

The downstream reference reach was identified approximately 315 feet downstream of the culvert outlet (Figure 1). BFW measurement 4 was taken within this reach. The channel is relatively straight with a steeper channel slope than the upstream reference reach. Comparison of this reference reach slope to the longitudinal profile from survey data, appears to better match the longitudinal profile slope. While the slope is steeper in the downstream refence reach, the cross section geometry is very similar to that found in the upstream reference reach. Site conditions of the reference reach where the bankfull width measurement was taken can be viewed in Figure 16.

During the second site visit with HDR, WSDOT, WDFW, and the Suquamish Tribe the reference reach and proposed channel cross section was determined to be appropriate.

Data Collection:

Describe who was involved, extents collection occurred within

HDR conducted an independent site visit on April 5, 2021. HDR walked the stream approximately 400 feet upstream and approximately 350 feet downstream of the existing culvert crossing. HDR took four bankfull width measurements and two pebble counts within these extents. Figure 1 illustrates the locations of the data collected during the site visit.

Observations:

Describe site conditions, channel geomorphology, habitat type and location, flow splits, LWM location and quantity, etc.

Upstream Reach

The upstream reach is characterized by a riffle pool morphology, meandering plan form, abundant LWM, and a bed comprised of gravel and sand. At the start of the upstream topographic survey limits the flow is immediately directed to the right bank by a channel-spanning log jam, see Figure 4. The flow then widens out to a relatively straight, shallow section with gravel bars along each bank. This is where the first BFW measurement (BFW 1) was taken, as shown in Figure 5. LWM along the left bank then constricts the channel again, which then flows under a channel-spanning log.

Downstream of the log, the channel returns to a wide flat section with a slight left bend. A natural log weir creates a small water surface drop and a steep left bank and the cedar stump forces the flow right. The main channel then takes a 180 degree bend to the right, thus forming a gravel point bar on the inside of the bend. A small tributary (Tributary 1) enters the left bank (Figure 6) of the main channel in the middle the bend. The tributary substrate is a sandy gravelly mix slightly smaller than that observed in the main channel. Several stormwater outfalls drain to this tributary. In the same vicinity of the tributary, groundwater seeps were observed and identified by orange colored soils and hydric vegetation (skunk cabbage).

Coming out of the 180 degree bend, the thalweg migrates toward the right bank of the channel. The right bank in this straight section has a 2 to 3 foot right bank. As the main channel straightens out there is another channel-spanning log several feet above the water surface. This is where BFW 2 was taken and the upstream reference reach was identified, see Figure 7. As the channel meanders to the right, gravel bars form on the left side of the channel, resulting in an

asymmetrical channel shape. The channel has access to a wide flat floodplain along the left bank which is characterized by saturated soils and hydric vegetation until it meets the road embankment at the culvert inlet.

Downstream of the reference reach, the channel turns 90 degrees north before straightening out again. LWM on the left bank directs the channel against the right bank and then opens up to a straight section containing a mid-channel bar, shown in Figure 8. A small tributary (Tributary 2) enters the channel along the right bank at the mid-channel bar. This tributary has no known stormwater inputs but has similar features along it as found in Tributary 1 including groundwater seeps, saturated soils, and hydric vegetation. Downstream of the mid-channel bar, the channel narrows and flows under a log bridge formed between two stumps, see Figure 9. There is a gravel bar on the left side of the channel under the log bridge.

Approximately 20 feet downstream of the log bridge, flow continues under another large channel-spanning log. A third tributary (Tributary 3) enters the creek along the right bank approximately 30 feet upstream of the culvert inlet. This tributary is close to SR 166 and trash was observed along it, which may indicate stormwater inputs into the side channel. The tributary was incised up to two feet in places.

The existing culvert inlet is a 4 foot high by 4 foot wide four sided concrete box culvert. The culvert has 20 degree wingwalls, a short headwall, and a bottom apron that extends out as far as the wingwalls (Figure 10). The inlet did not have sediment accumulation in the bottom, but 10 feet downstream of the inlet the water surface drops approximate 1 foot due to accumulated woody material and large rocks. There was significant erosion along the left side of the inlet and behind the left wingwall. Flow at the culvert entrance was less than 6 inches deep and visually estimated at 3-5 cubic feet per second on the day of the site visit. Road fill slopes on both sides of the crossing exceed 2:1.

As a whole the planform of the upstream channel can be characterized as a single-threaded channel with a riffle-pool morphology and abundant LWM.

Homeless encampments have been established in the upstream reach adjacent to the stream and appear to be responsible for trash and waste in the stream channel.

Downstream Reach

The downstream end of the culvert is the same size and material as at the inlet end. The headwall and wingwalls are skewed slightly to the right to direct flows in a more downstream direction. Large angular rock and accumulated woody material at the outlet create backwater within the culvert, so that the culvert was half full of streambed material as shown in Figure 11. Immediately downstream of the culvert, the channel travels through a large pool formed by large angular rock and LWM, and then cascades down to a 90 degree bend. The bend to the right approximately 15 feet downstream of the culvert outlet has a moderate amount of bank erosion from the bend near the culvert outlet. The channel then flows parallel to SR 166 for approximately 100 feet. This section is highly confined by the road fill slope on the right bank and steep left bank for the first 50 feet downstream of the culvert inlet. This section contains large downed trees and recently cleared vegetation and far less understory vegetation overall than in the upstream section, see Figure 12. There was also some angular rock mixed in with the rounded rock in this section, likely recruited from the road embankment. The channel then bends to the left and some potential floodplain access opens on the left. The right bank is steep through this bend and there was minor bank undercutting.

As the channel straightens out there are two approximately 3 foot diameter logs spaced 10 feet apart across the channel. The water surface was at or within approximately 6 inches of the bottom of the logs and the channel width was narrowed through the section. At high flow events these two logs likely create backwater as flow is forced under them, see Figure 13. Downstream of the logs the channel returns to its more typical section seen upstream of the crossing with abundant LWM, complexity, and has floodplain access above both banks. The channel width is initially constricted by a LWM piece along the right bank then it widens downstream. Fine-grained sediment is deposited behind a LWM piece positioned parallel along the right bank. This is where BFW 3 was taken as seen in Figure 14.

Downstream of the BFW 3 measurement, there is a long parallel piece of LWM along the right bank that diverts flow to the left side of the channel. There is fine sediment deposited behind the log and a point bar on the inside of the bend. There is also a marked increase in understory vegetation in this section. Further downstream, within about 25 feet there is a large log on the left bank diverts flow back to the right. Within this section there are multiple pieces of LWM spanning and running lengthwise along the channel resulting in small water surface drops and forming deep pools (Figure 15). The channel then straightens out for a short section and increases in slope, which carries through and

beyond the downstream topographic and reconnaissance survey extents. BFW 4 was taken just upstream of the topographic survey limits as shown in Figure 16. This was also the location of the downstream reference reach and where the second pebble count took place. The largest natural particle size observed in the downstream reach was 5 inches.

As a whole the planform of the downstream channel can be characterized as a single-threaded channel with a riffle-pool morphology and abundant LWM.

Pebble Counts:

Describe location of pebble counts if available

Two pebble counts each of approximately 150 particles were performed. One upstream of the culvert and one downstream. Both pebble counts were done in the respective reference reaches, which are shown in Figure 1. Counts of 150 particles were deemed appropriate because of the length of the reference reach and the similar material size observed outside of the reference reach. The cumulative distribution and specific pebble sediment sizes are provided in Figure 2 and Table 2. Material primarily consisted of fine to coarse gravels and sand as shown in Figure 3.

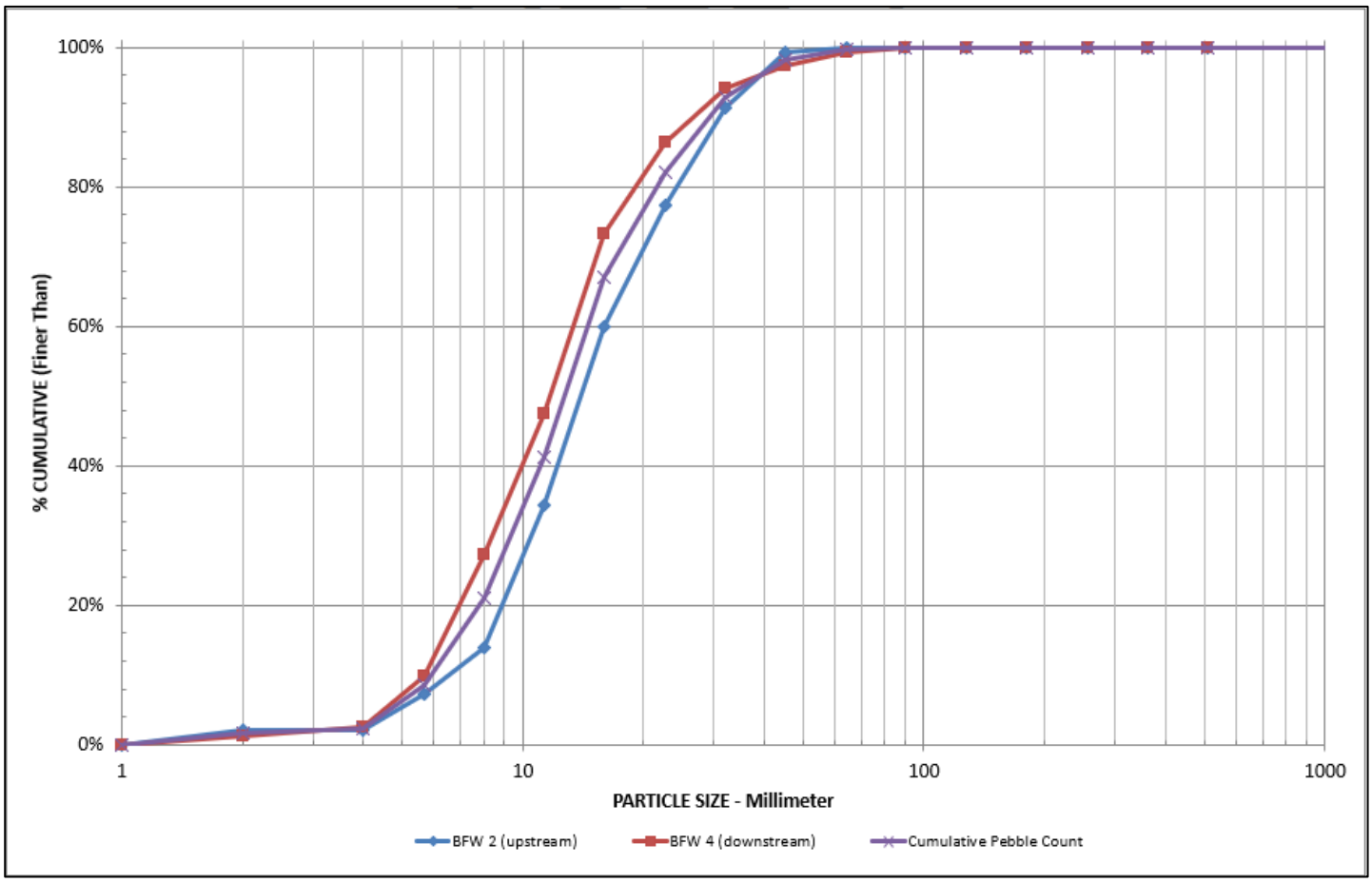


Figure 2: Sediment size distribution

Table 2: Observed streambed sediment size

	BFW 2 (upstream)		BFW 4 (downstream)		Cumulative	
Particle	**Diam. (in)**	**Diam. (mm)**	**Diam. (in)**	**Diam. (mm)**	**Diam. (in)**	**Diam. (mm)**
$\mathbf{D_{16}}$	0.3	8.2	0.2	6.3	0.3	6.8
$\mathbf{D_{50}}$	0.6	14.0	0.5	11.7	0.5	12.7
$\mathbf{D_{84}}$	1.0	26.3	0.8	21.2	0.9	23.5
$\mathbf{D_{95}}$	1.5	37.5	1.4	35.0	1.4	36.7

D_{100}	2.5	64.0	3.5	90.0	3.0	76.2

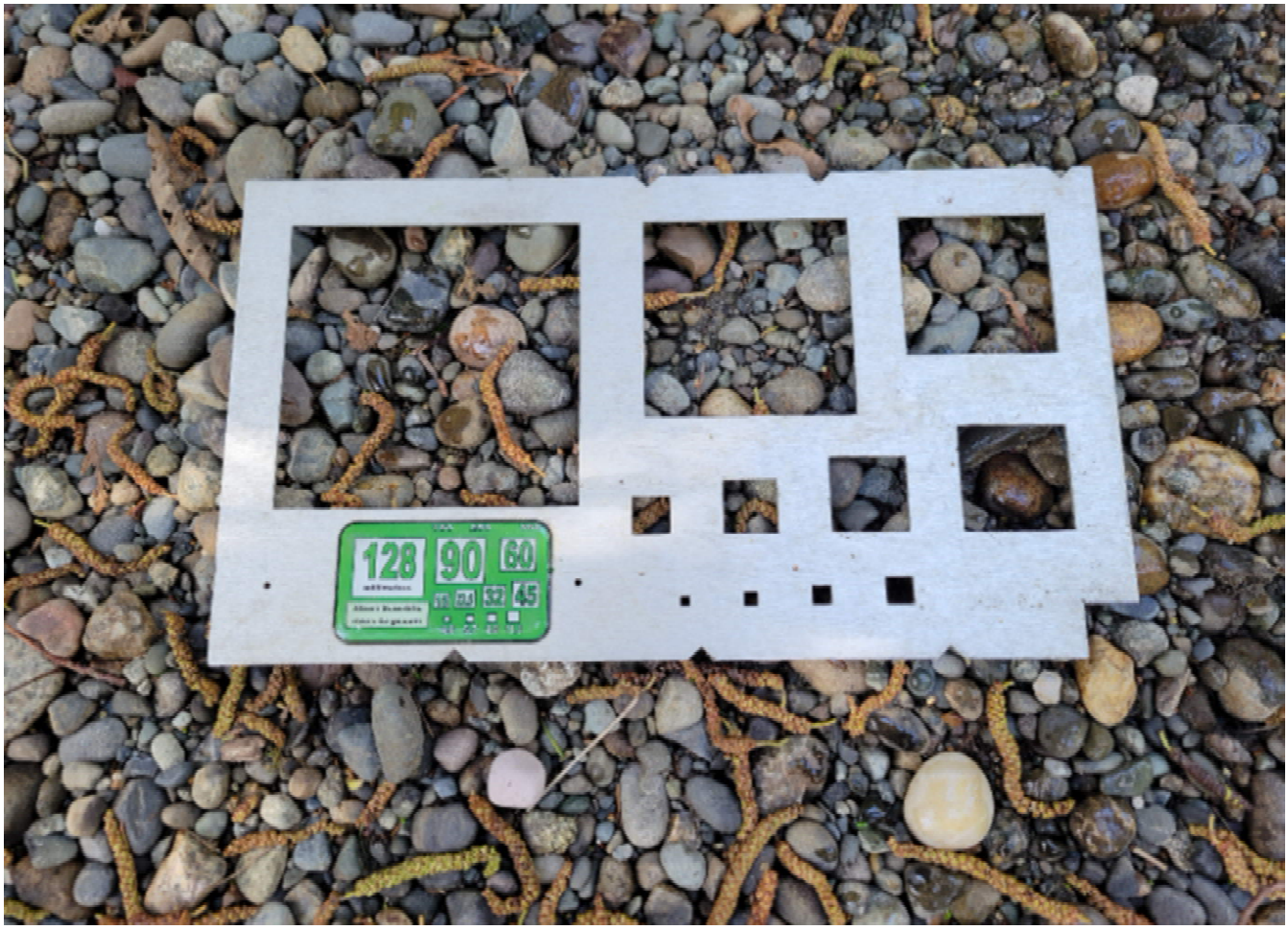


Figure 3: Representation of sediment size

Photos:

Figure 4: Upstream survey extents looking downstream

Figure 5: BFW 1 looking upstream

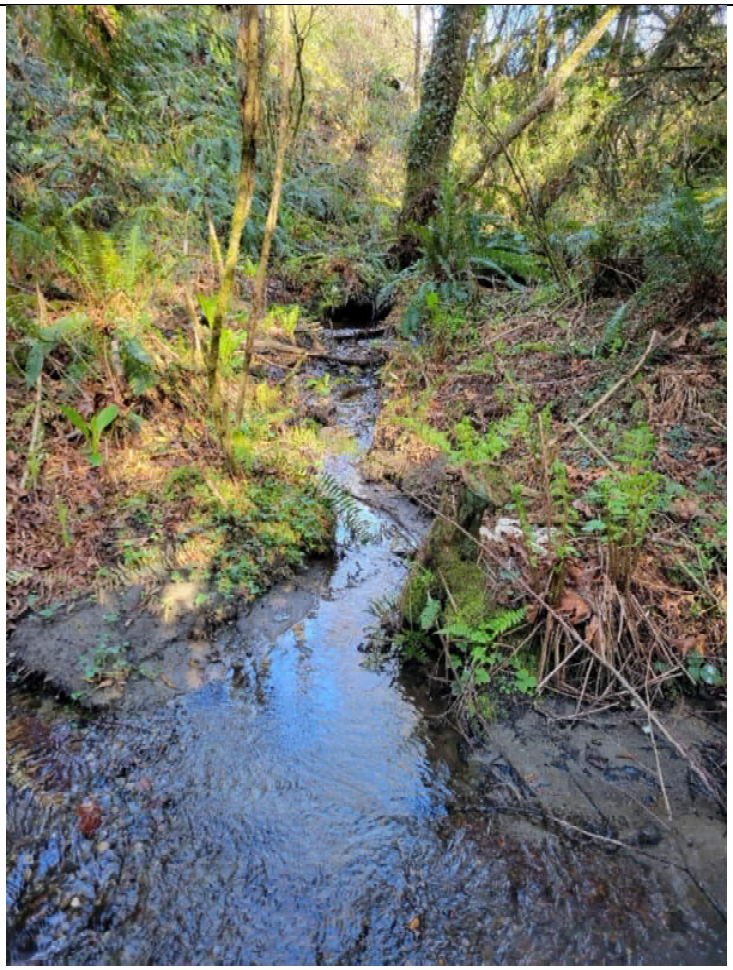


Figure 6: Tributary 1 enters Olney Creek at bottom of photo

Figure 7: BFW 2 looking upstream

Figure 8: Mid-channel bar looking downstream

Figure 9: Log bridge looking upstream

Figure 10: Culvert inlet

Figure 11: Culvert outlet

Figure 12: Straightened channel section looking upstream

Figure 13: LWM bridges looking downstream

Figure 14: BFW 3 looking downstream

Figure 15: LWM creating small drops and pools

Figure 16: BFW 4 looking downstream

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☒ If no, then stop here.*
	Yes ☐ If yes, then fill out the proceeding section for each sample.

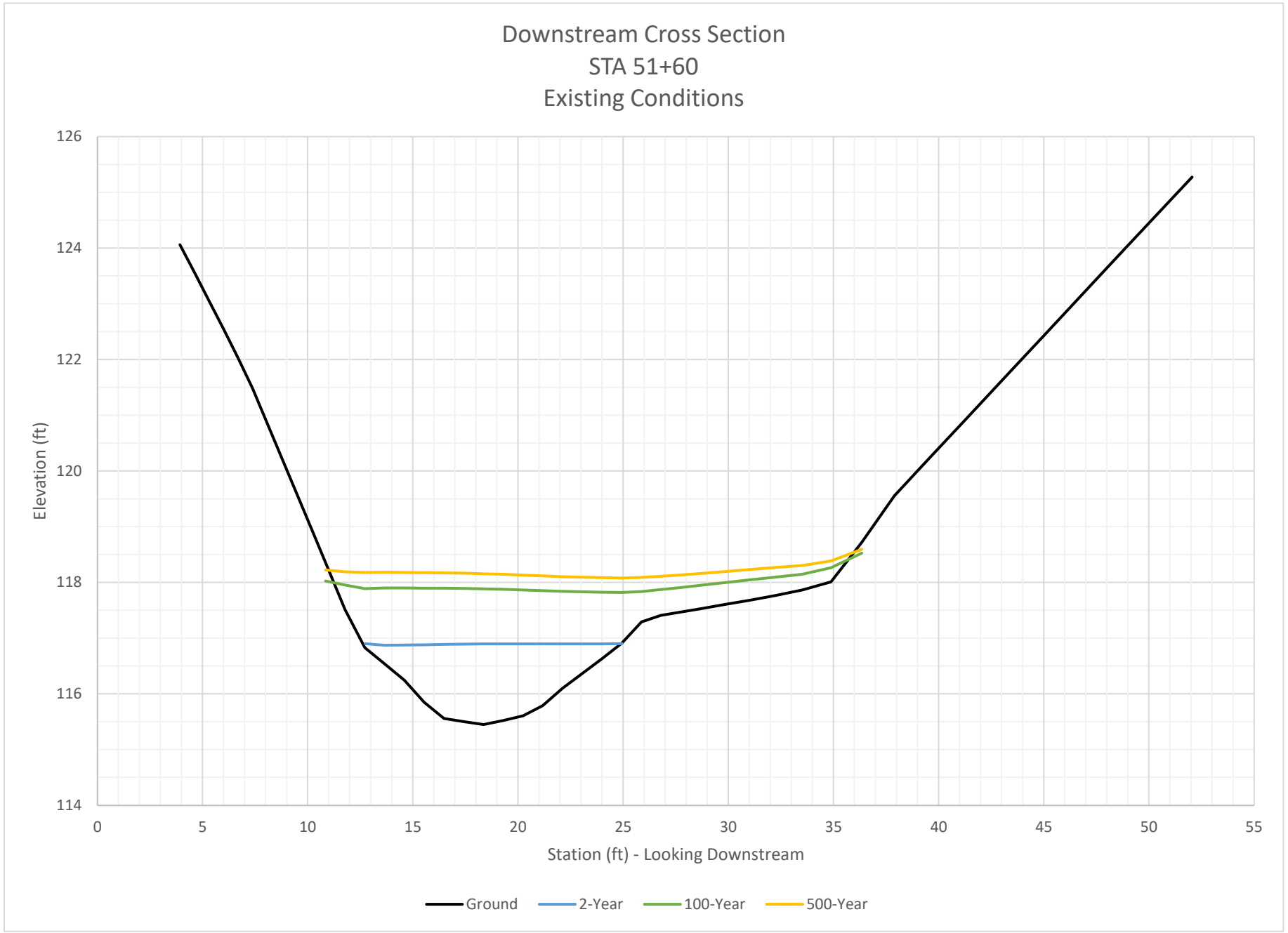
Sample #:	Work Start:	Work End:	Latitude:	Longitude:
Summary/description of location:				
Summarize/describe the sample location.				
Description of work below the OHWL:				
Describe the work below the OHWL, including equipment used and quantity of sediment sampled.				
Description of problems encountered:				
Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.				

Bankfull Width Concurrence Meeting:
Describe date and time of BFW concurrence meeting, attendees, any measurements, concurrence or decisions made that help to inform the design. You may have follow up information from this meeting and any follow up may be documented here as well. A second site visit with HDR, WSDOT, WDFW, and the Suquamish Tribe was conducted on September 22, 2021 to gain concurrence on BFWs and other design considerations for Olney Creek at SR 166. During the site visit WDFW and WSDOT took spot BFW measurements and concurred with several of the BFW measurements from the initial site visit.

BFW measurement 3 was increased slightly and one additional BFW measurement was collected downstream (BFW 5). The design average is presented in Table 1.

Valley width measurements were taken at two locations downstream, one at the BFW 3 location, which was 38 feet, and a second at the BFW 5 location, which was 36 feet. These measurements are not anticipated to affect the MHO design, but more as an informational data point. WDFW requested that WSDOT inquire about wildlife habitat connectivity at the site when seeking information for another nearby site since the Olney Creek corridor provides green space connectivity through a highly urbanized area.

Appendix C: SRH-2D Model Results


Downstream Cross Section
STA 51+60
Existing Conditions
Elevation (ft)
126
124
122
120
118
116
114
0
5
10
15
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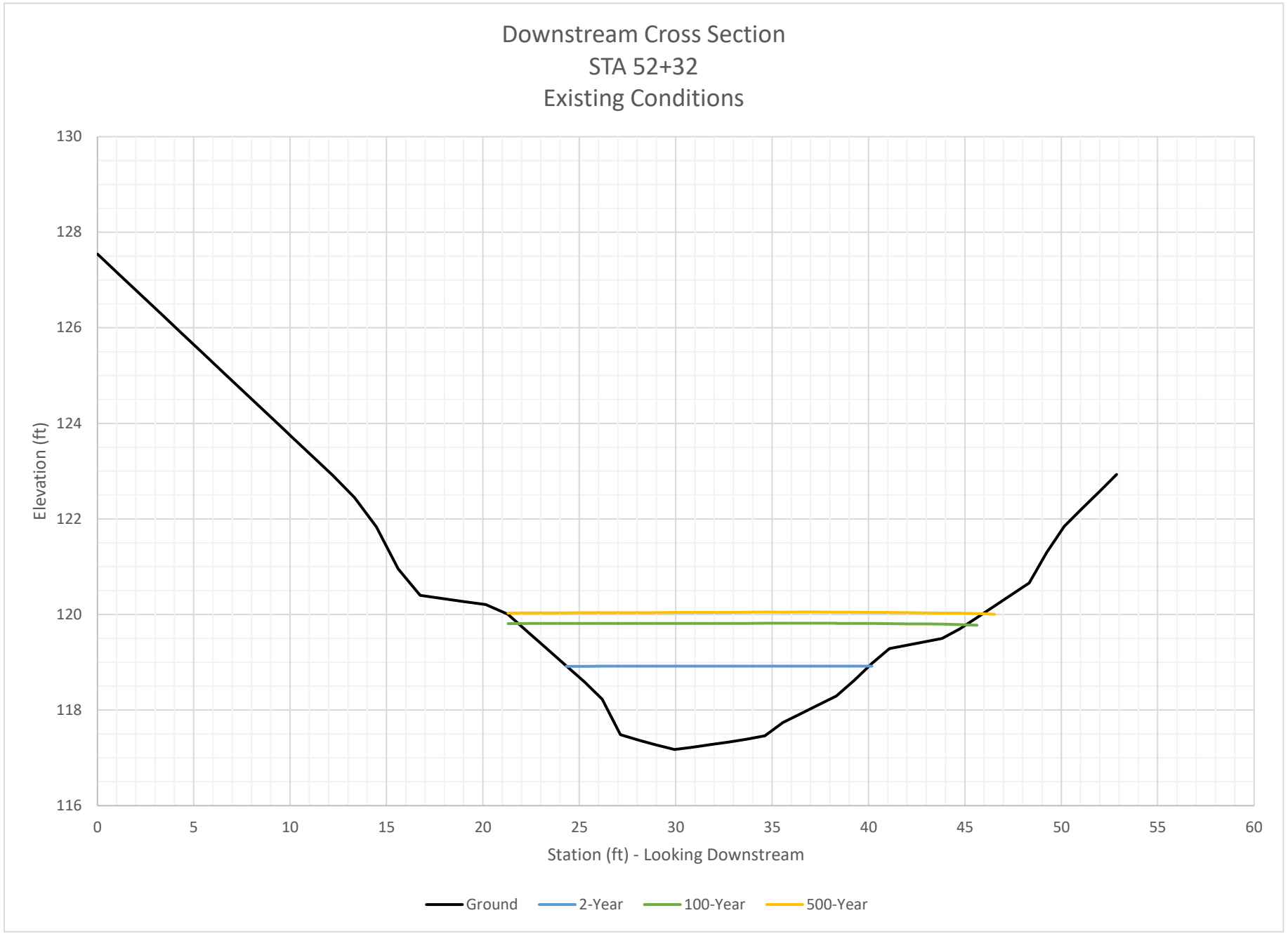
25
30
35
40
45
50
55
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year


Downstream Cross Section
STA 52+32
Existing Conditions
Elevation (ft)
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128
126
124
122
120
118
116
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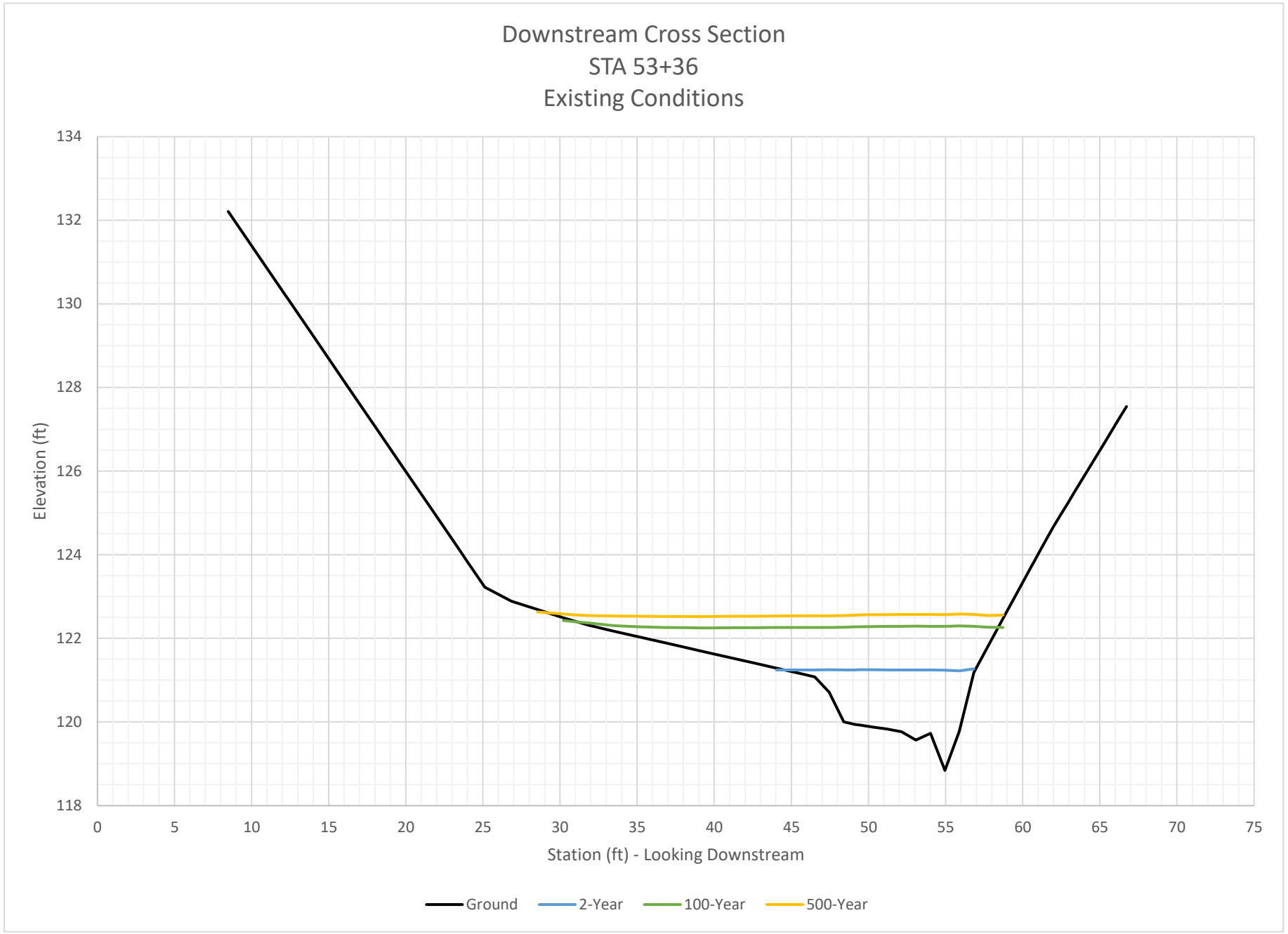
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year


Downstream Cross Section
STA 53+36
Existing Conditions
Elevation (ft)
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132
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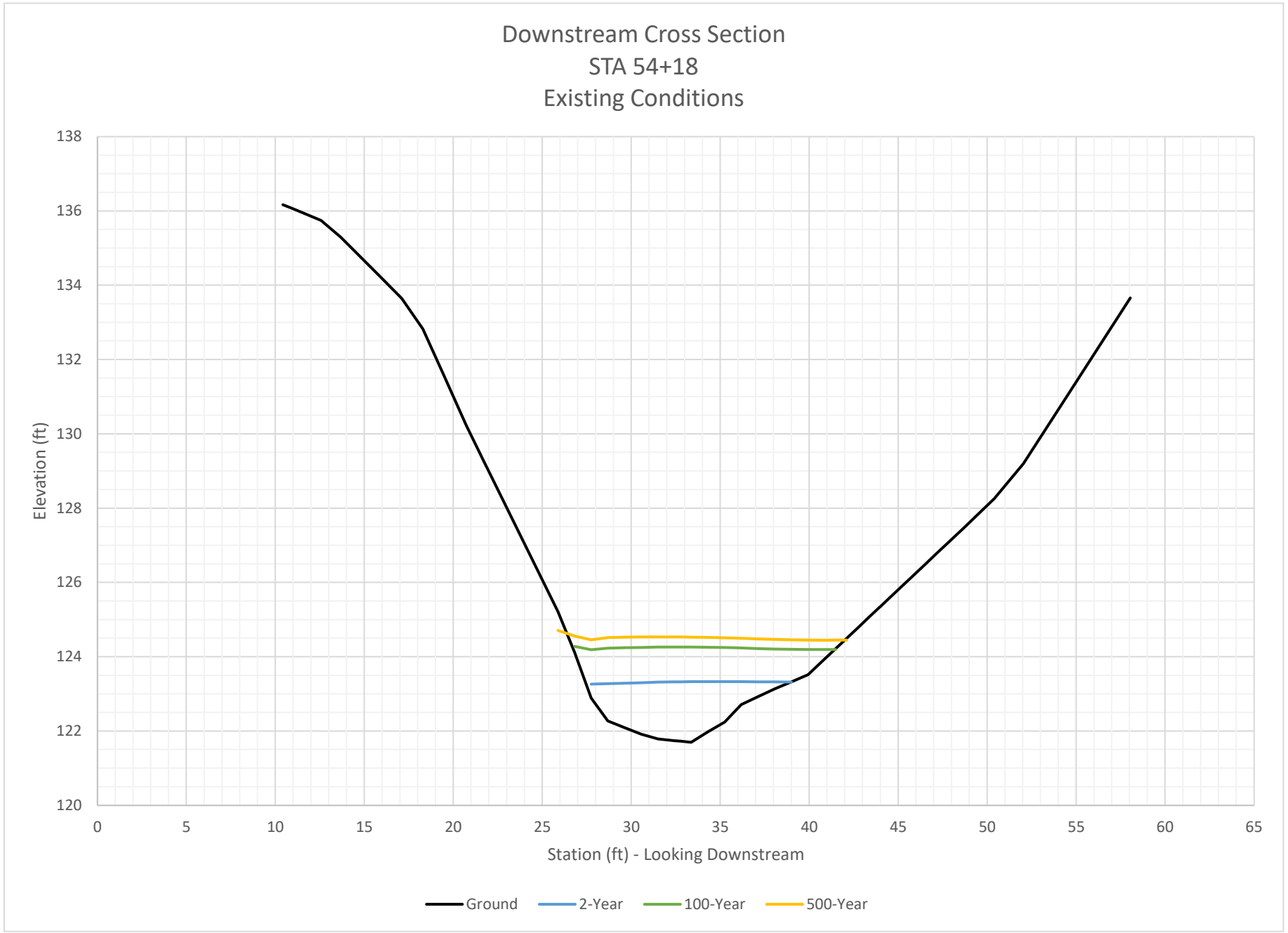
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year


Downstream Cross Section
STA 54+18
Existing Conditions
Elevation (ft)
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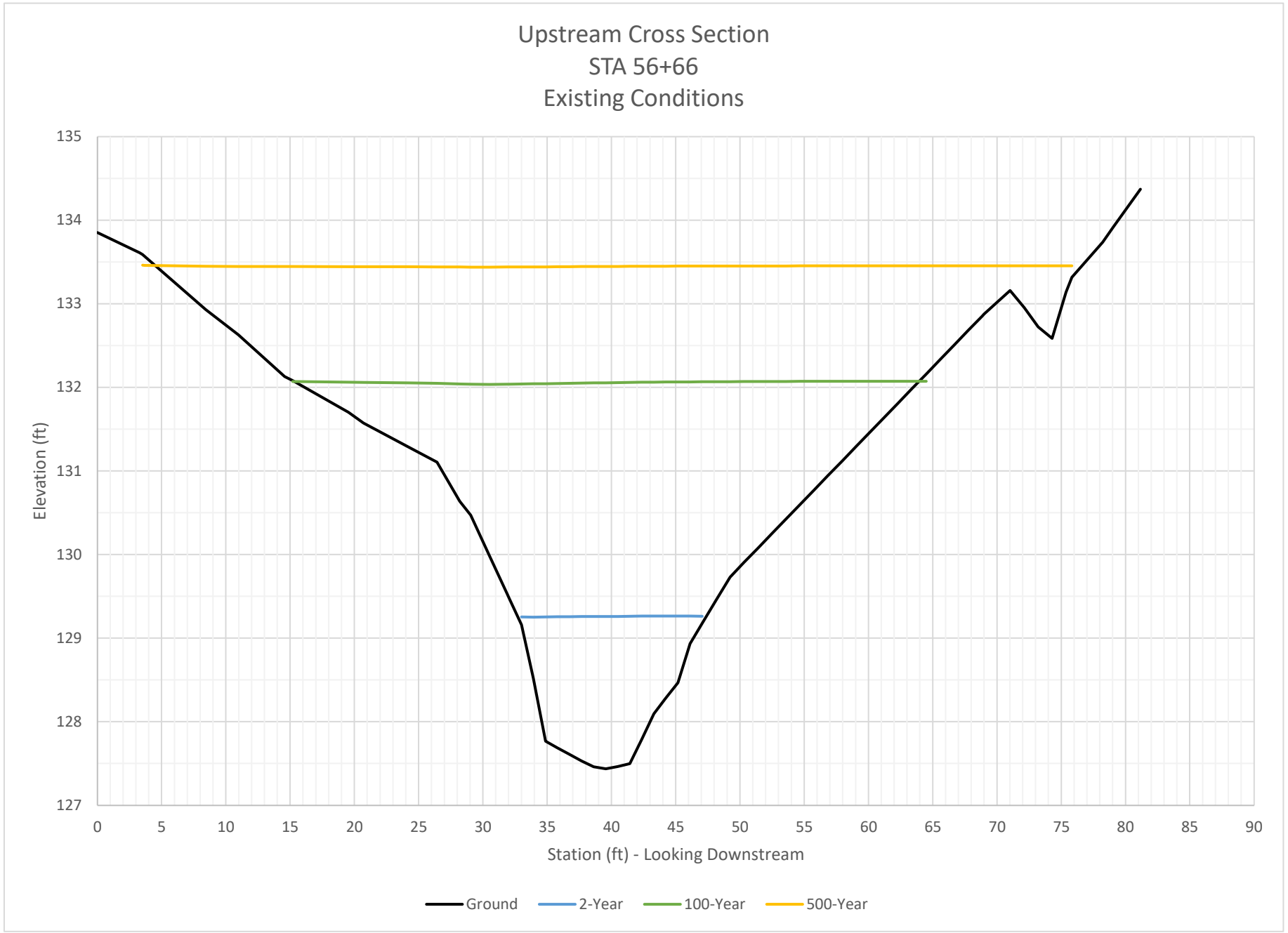
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year


Upstream Cross Section
STA 56+66
Existing Conditions
Elevation (ft)
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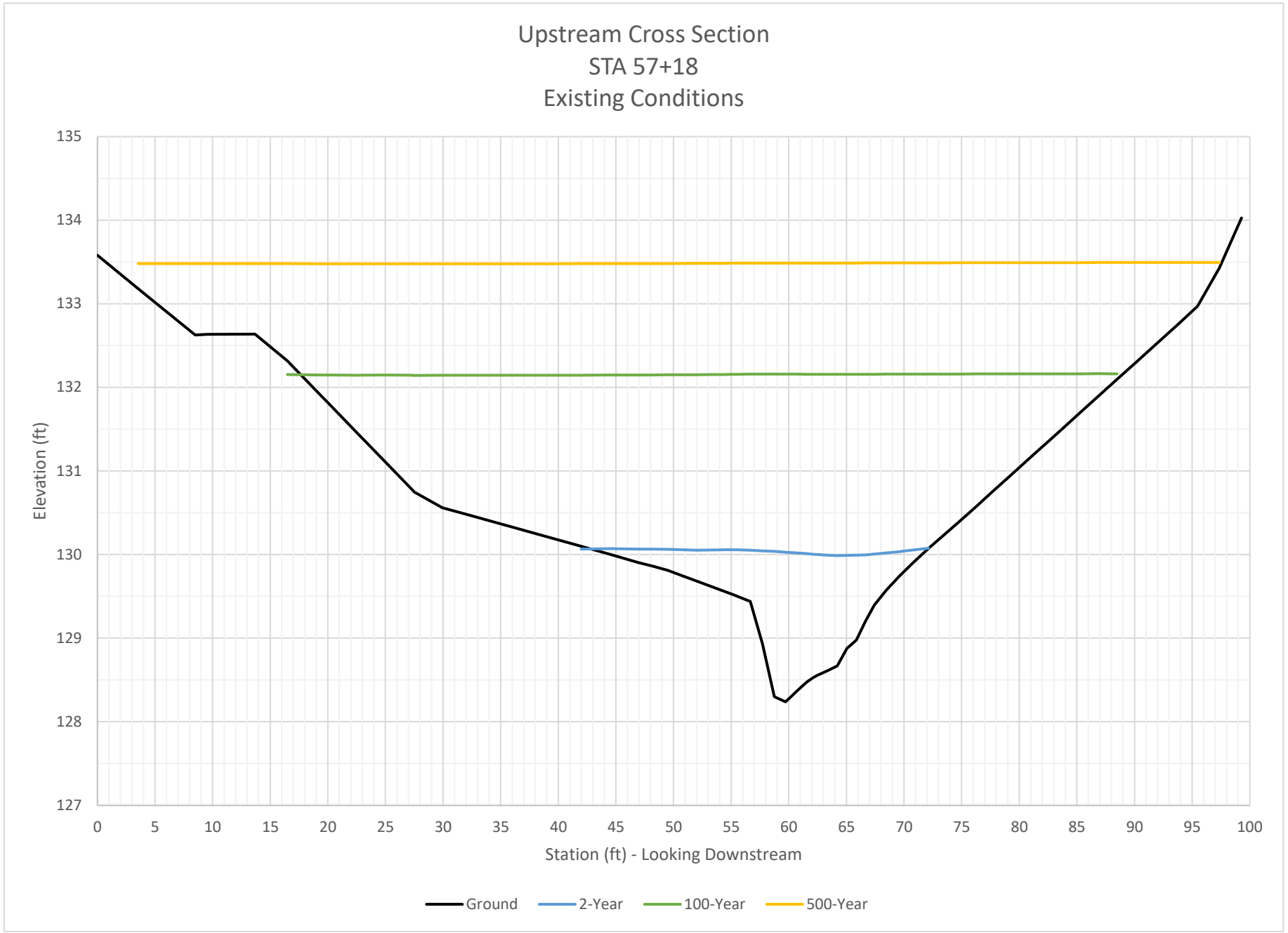
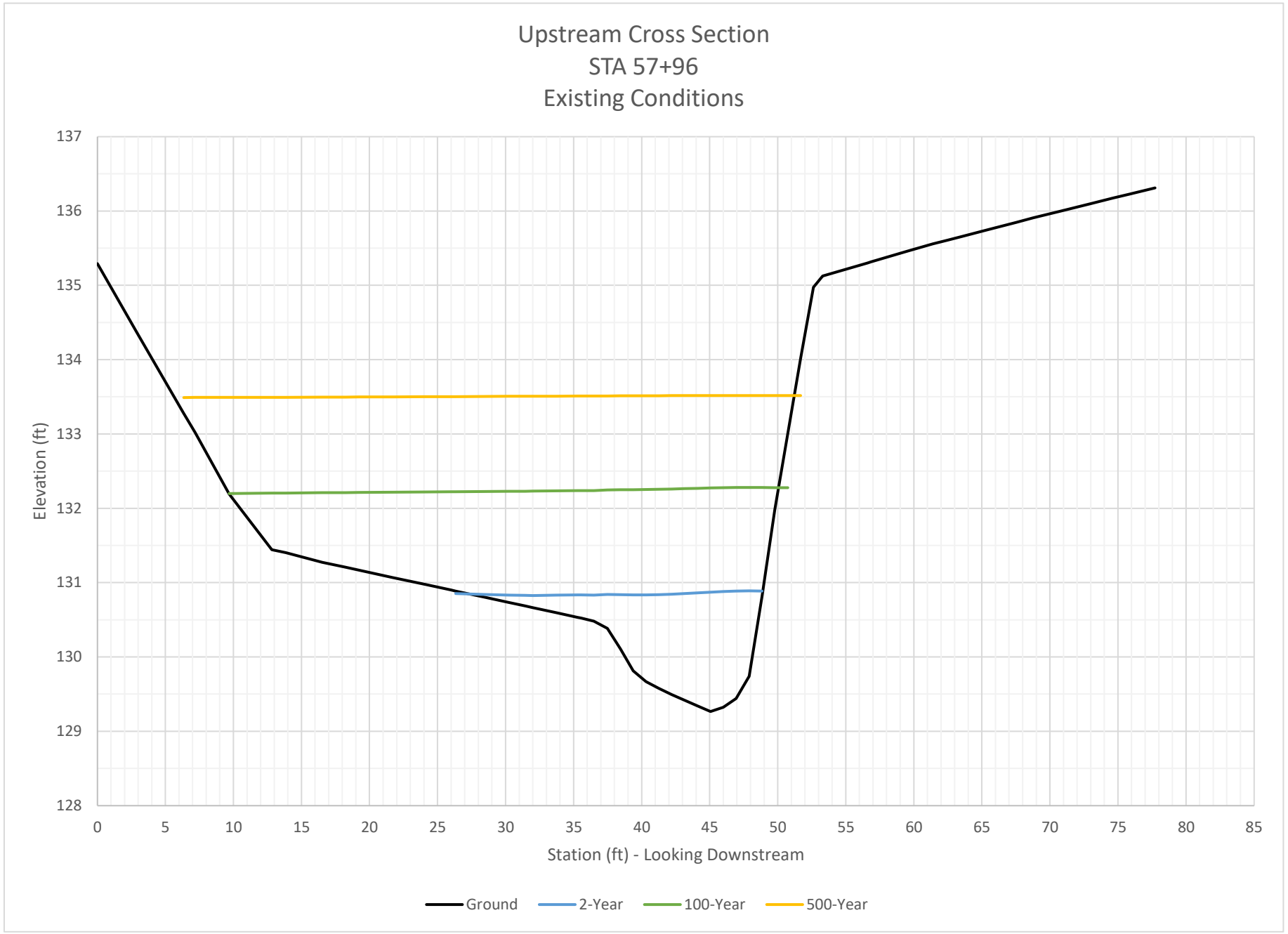
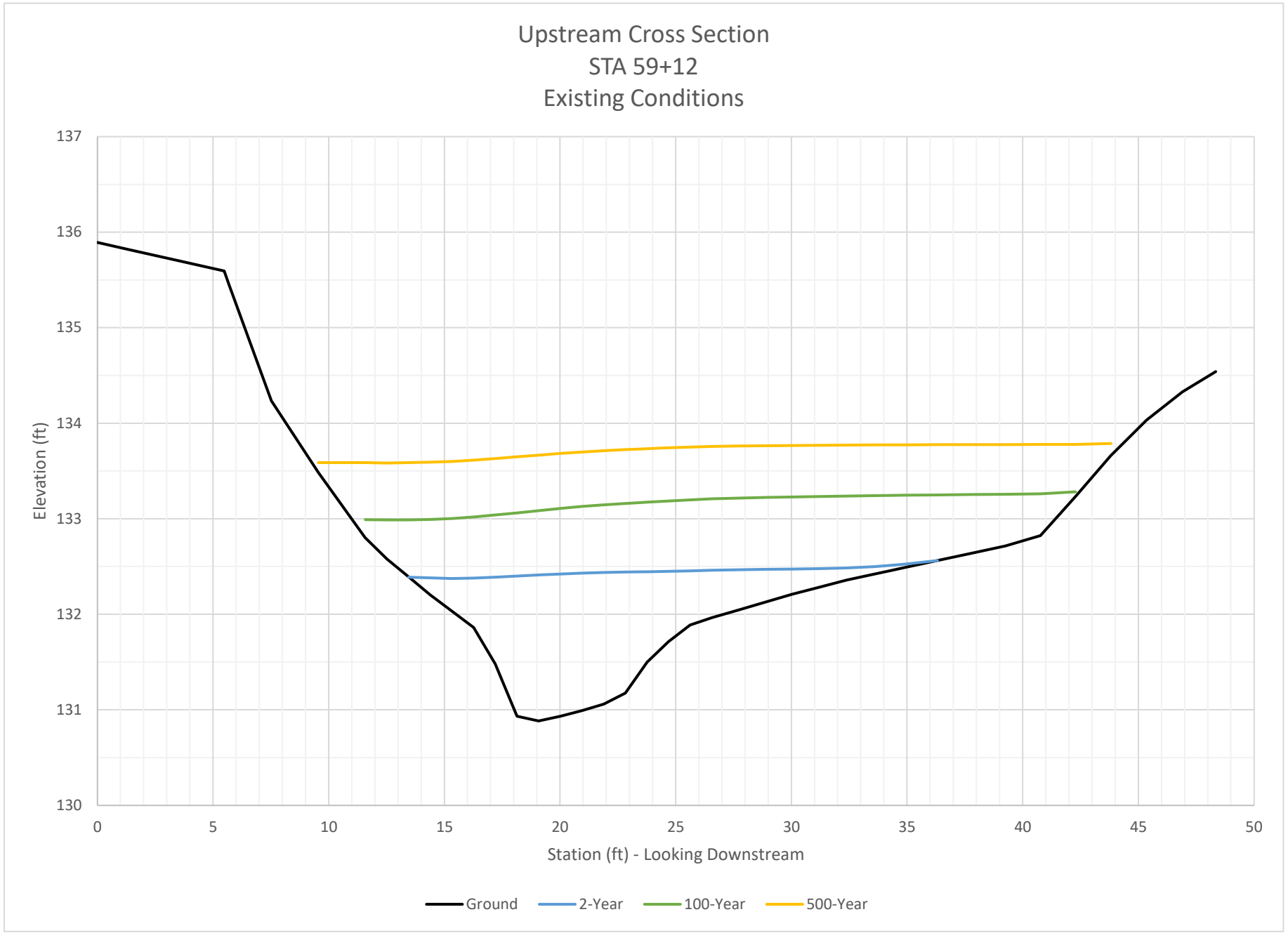
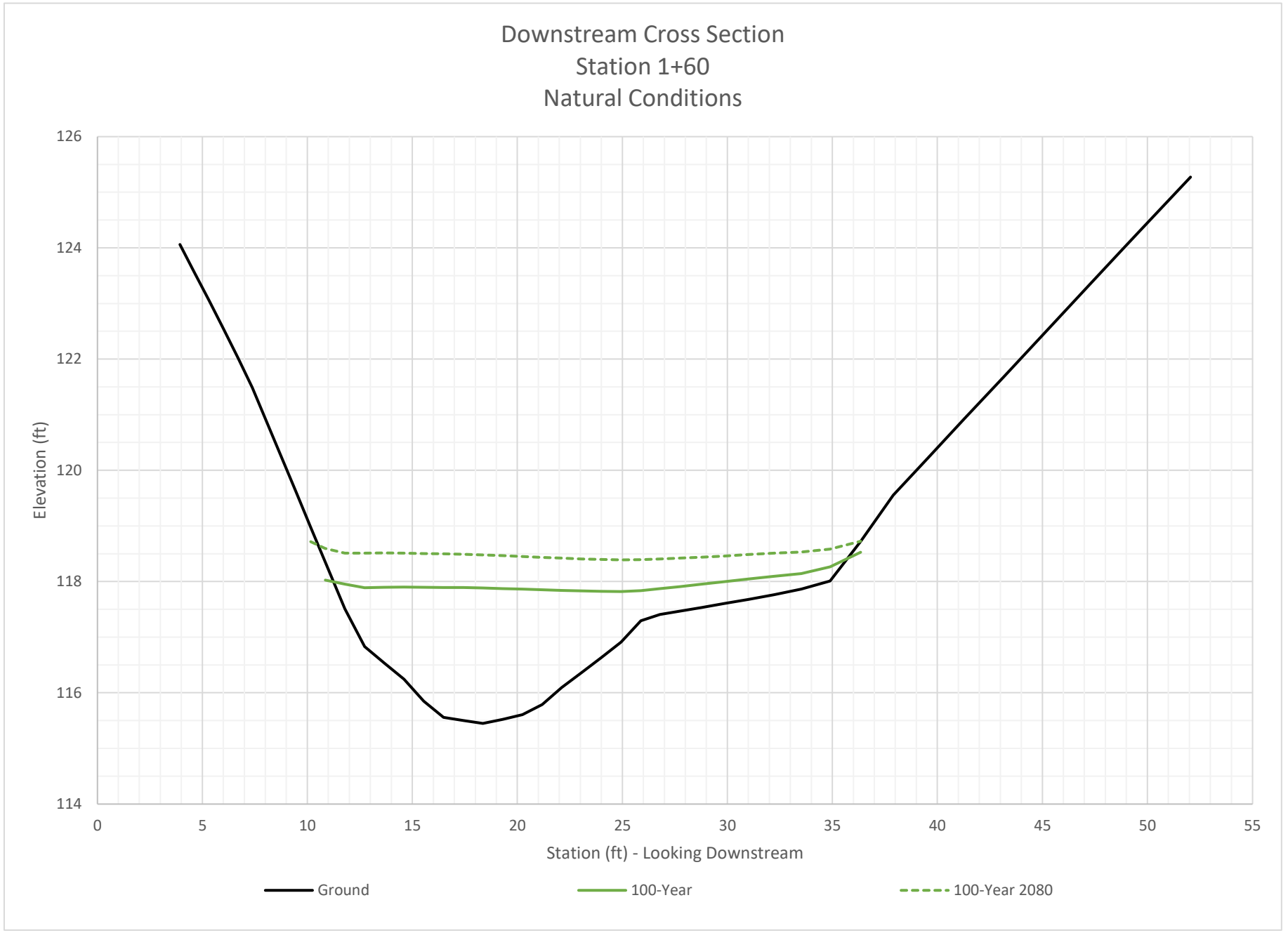
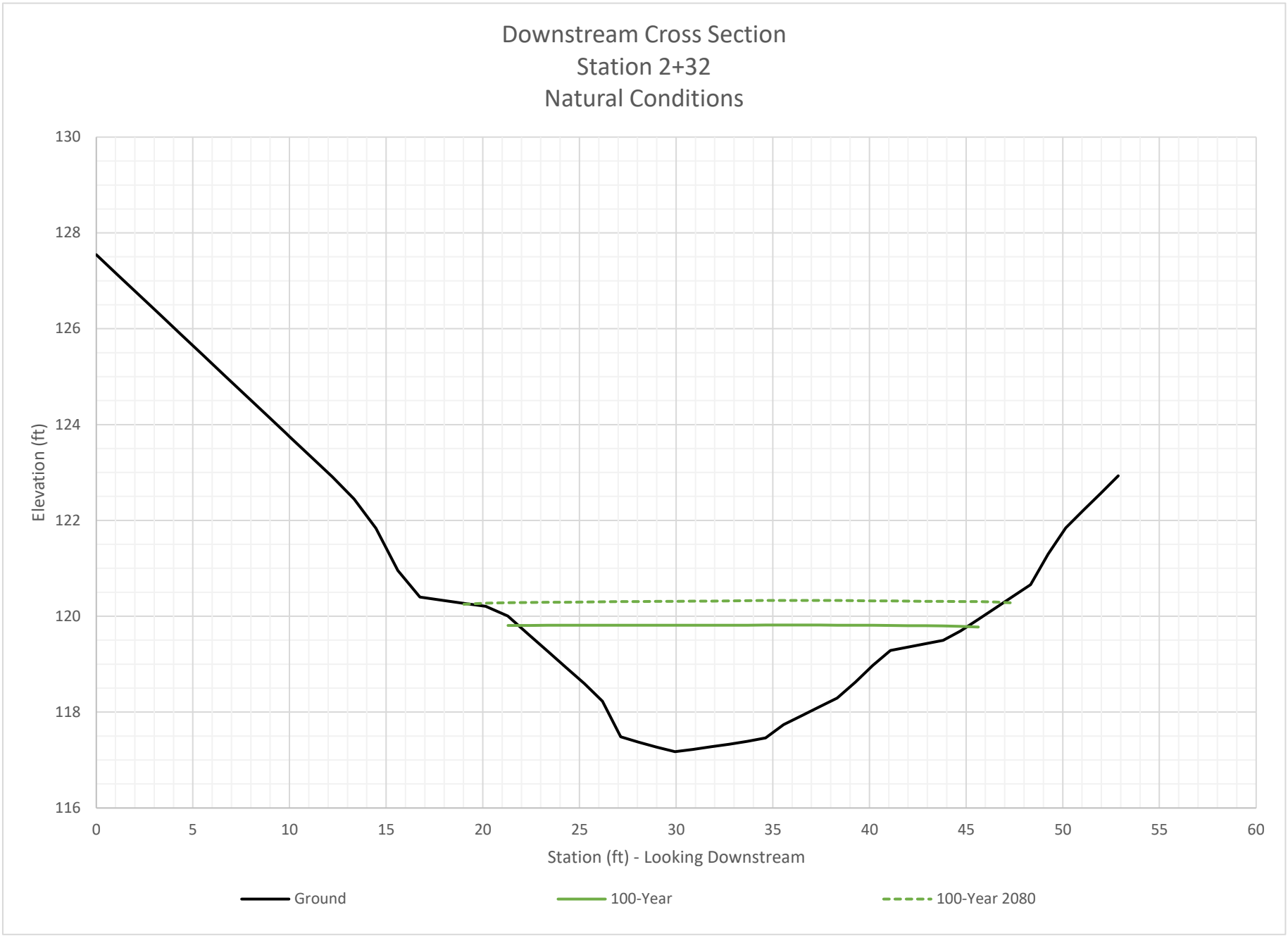
70
75
80
85
90
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year

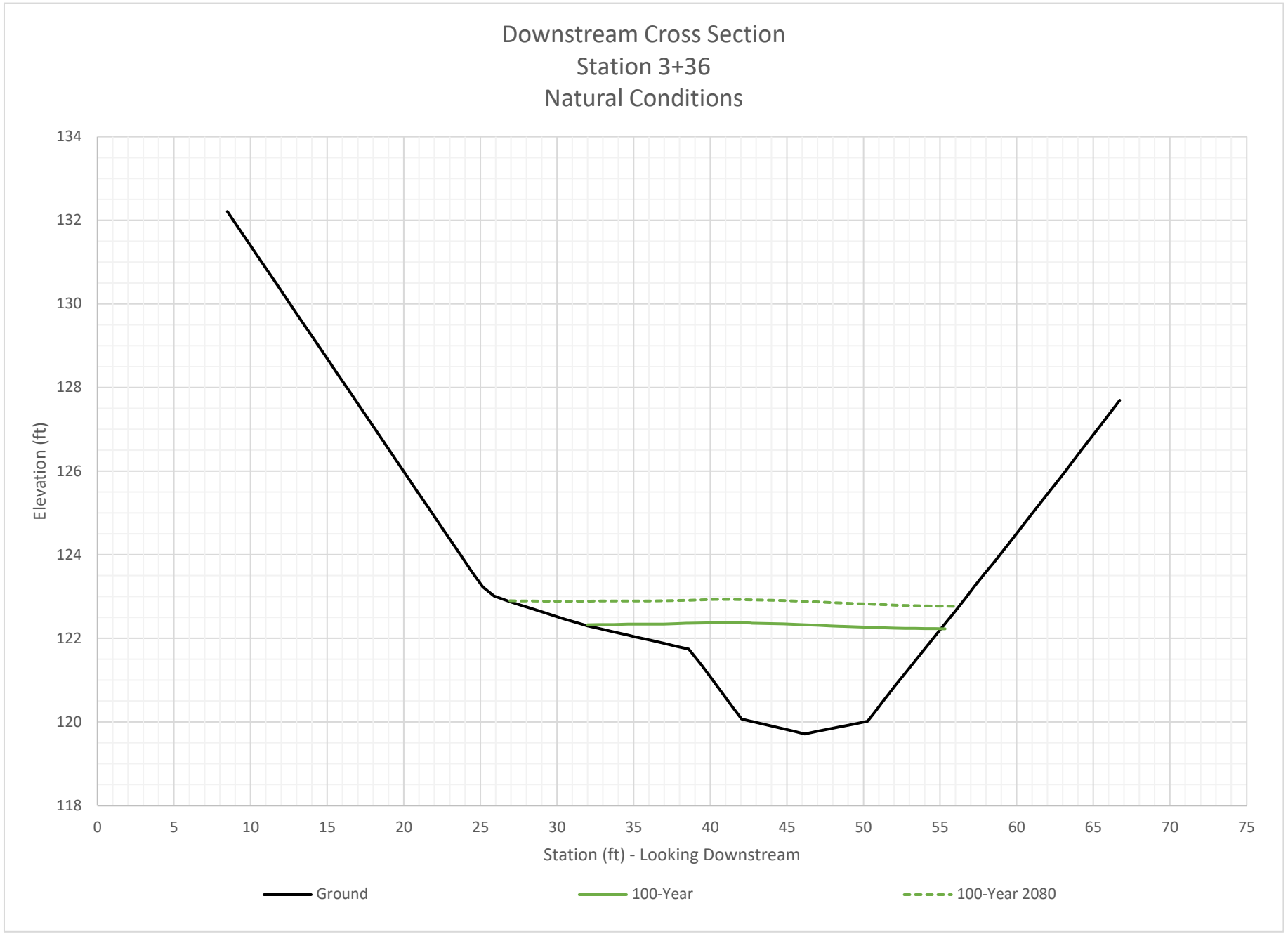

Upstream Cross Section
STA 57+18
Existing Conditions
Elevation (ft)
135
134
133
132
131
130
129
128
127
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year

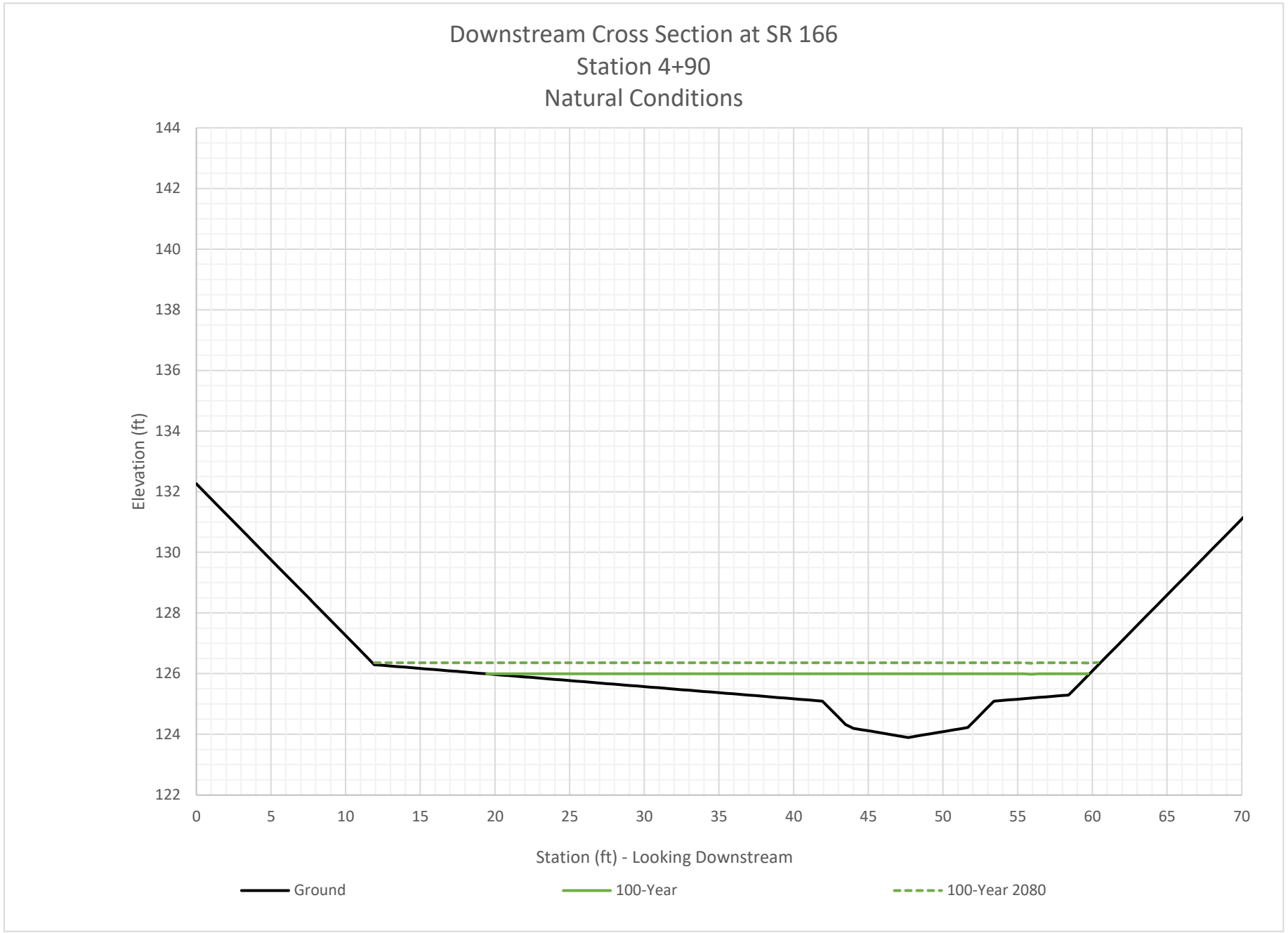

Upstream Cross Section
STA 57+96
Existing Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
129
128
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year

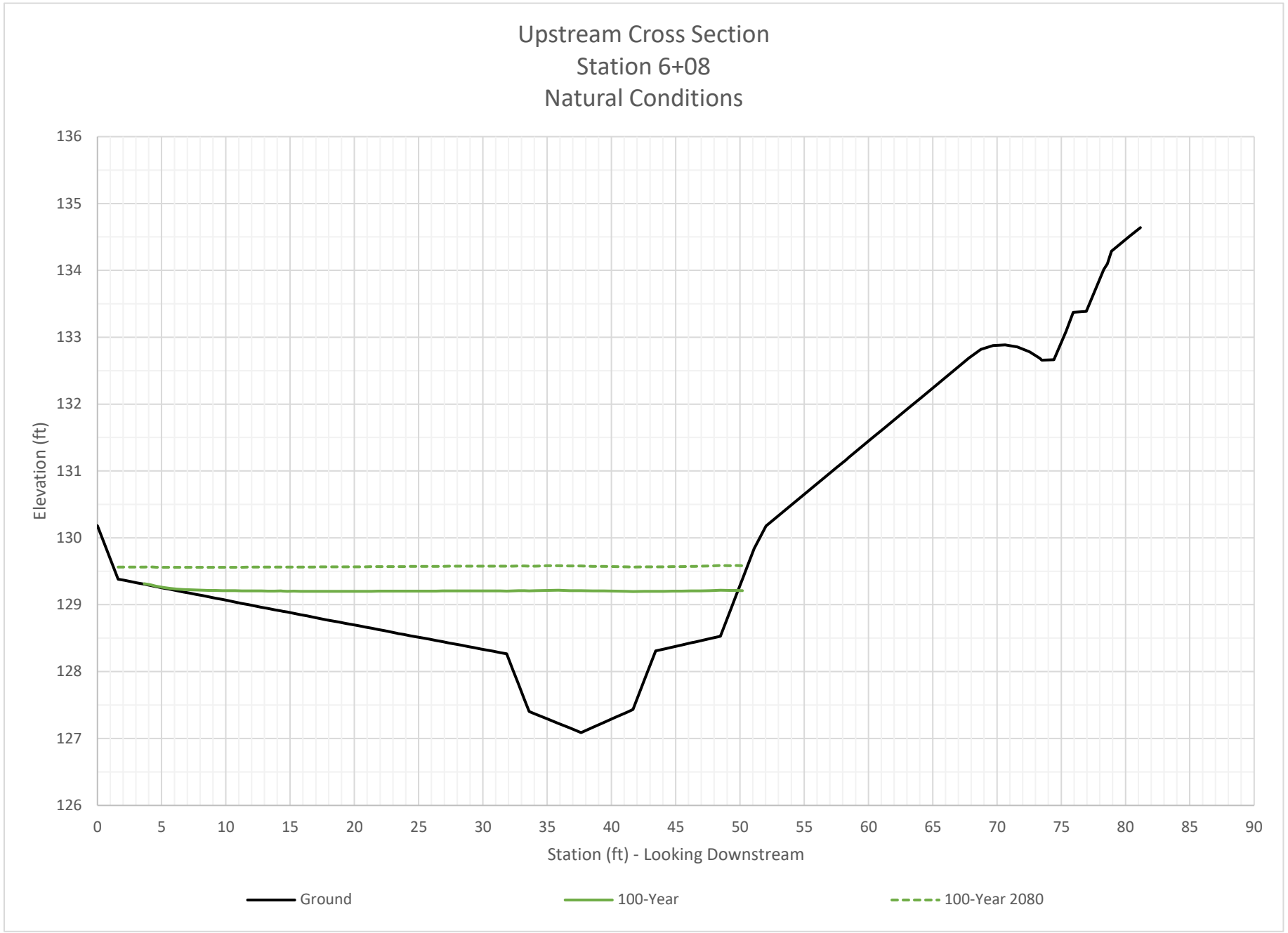

Upstream Cross Section
STA 59+12
Existing Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
0
5
10
15
20
25
30
35
40
45
50
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year

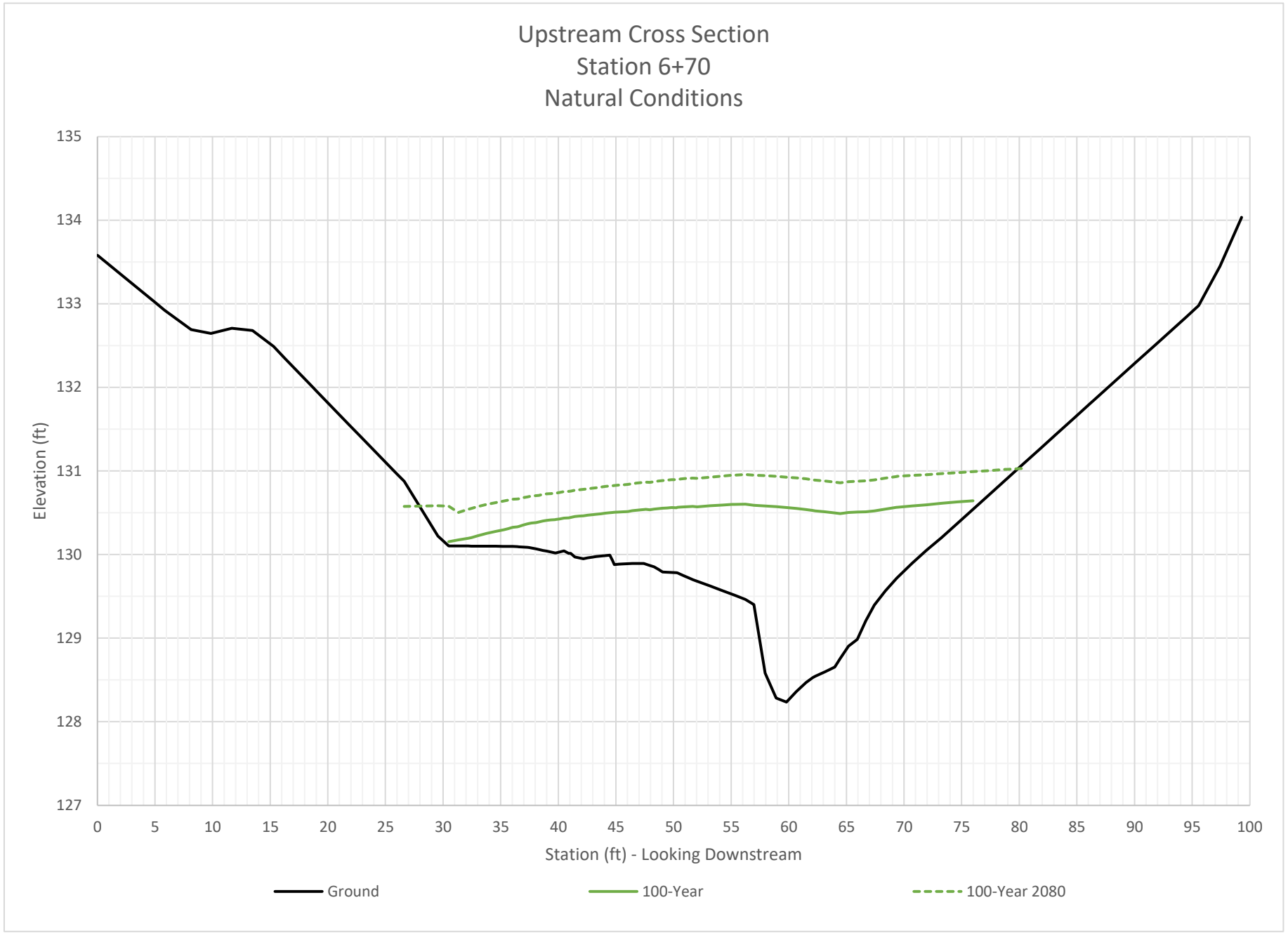

Downstream Cross Section
Station 1+60
Natural Conditions
126
124
122
120
118
116
114
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
50
55
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

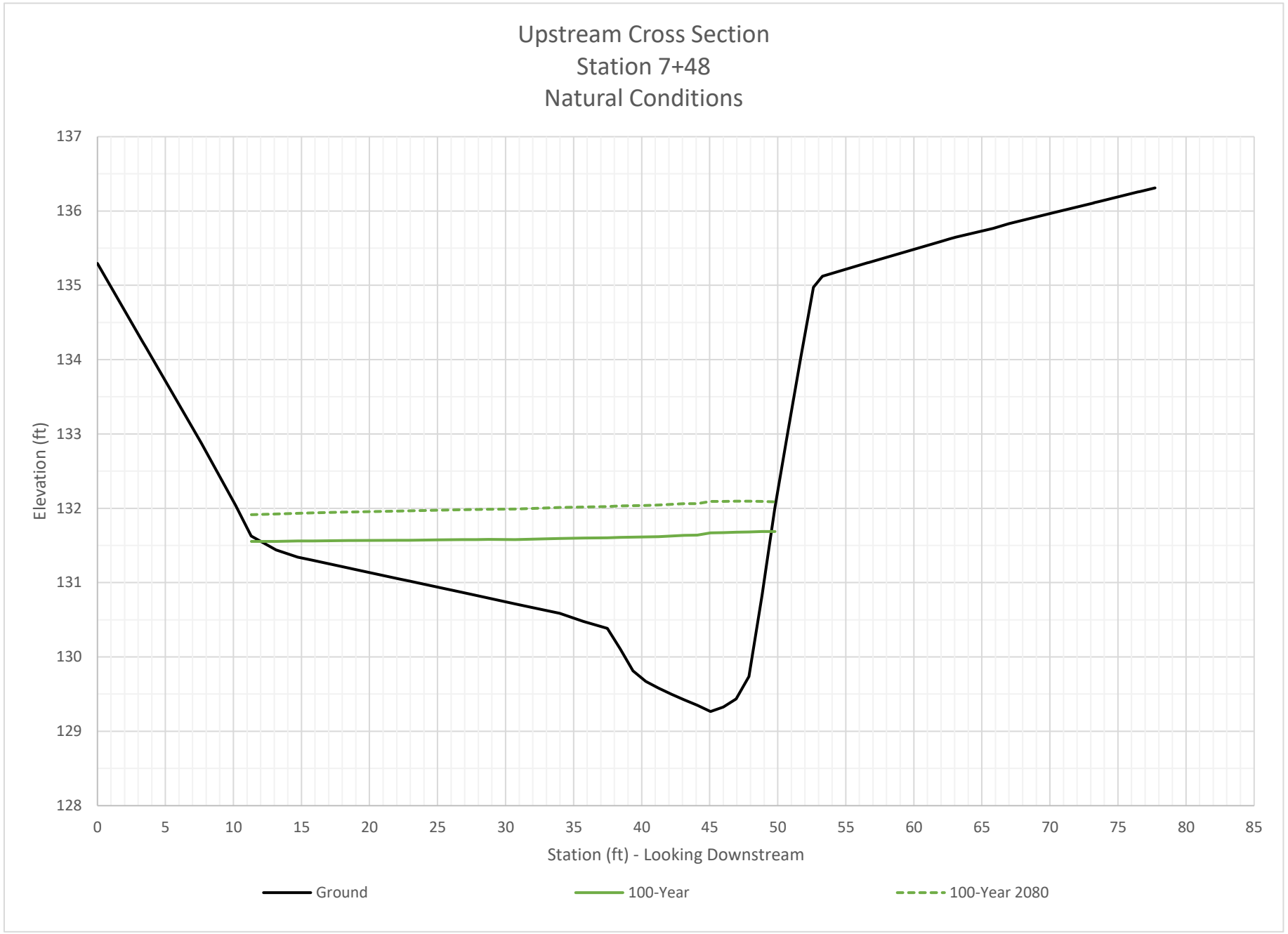

Downstream Cross Section
Station 2+32
Natural Conditions
Elevation (ft)
130
128
126
124
122
120
118
116
0
5
10
15
20
25
30
35
40
45
50
55
60
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

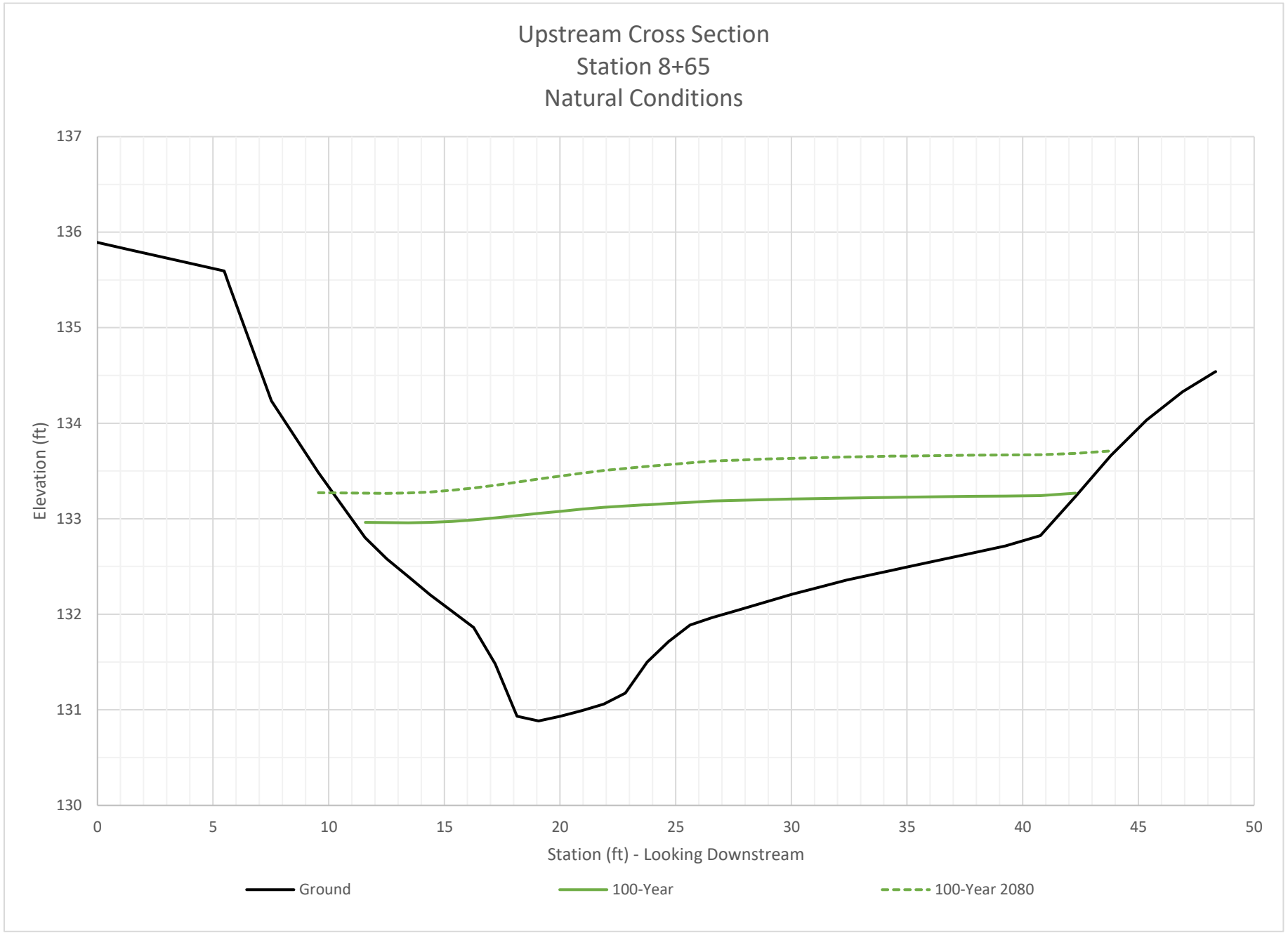

Downstream Cross Section
Station 3+36
Natural Conditions
Elevation (ft)
134
132
130
128
126
124
122
120
118
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

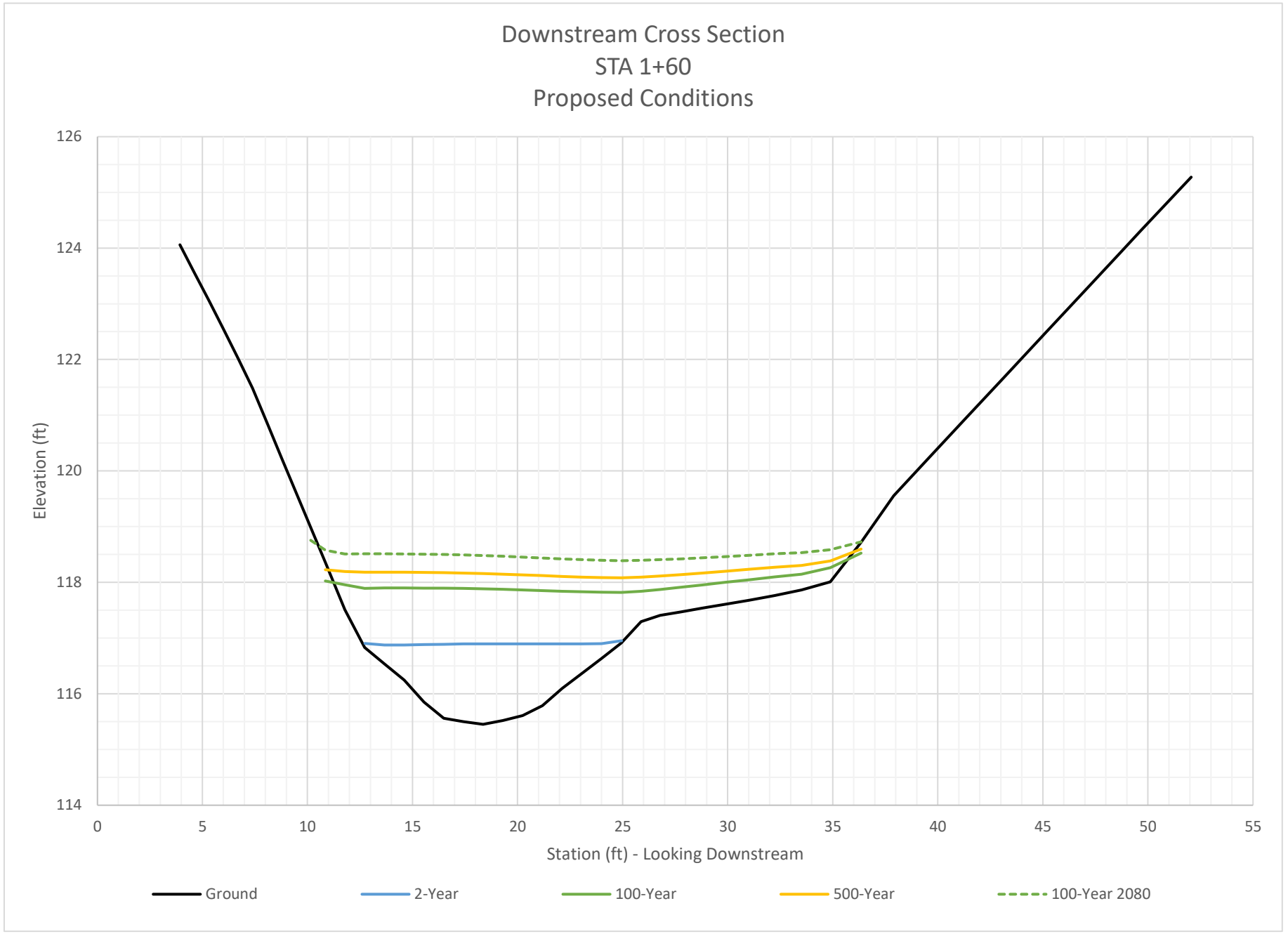

Downstream Cross Section at SR 166
Station 4+90
Natural Conditions
Elevation (ft)
144
142
140
138
136
134
132
130
128
126
124
122
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

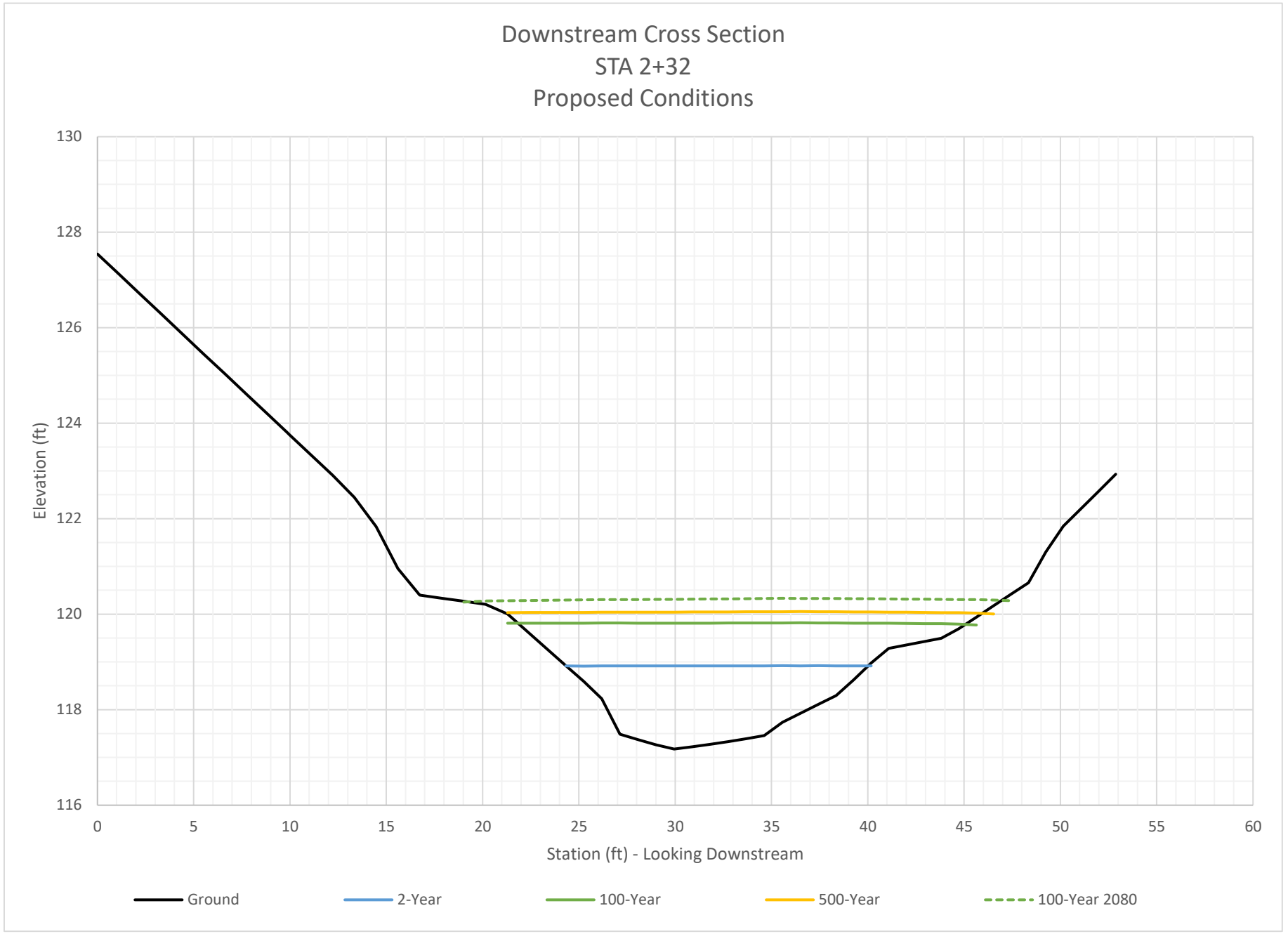

Upstream Cross Section
Station 6+08
Natural Conditions
Elevation (ft)
136
135
134
133
132
131
130
129
128
127
126
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

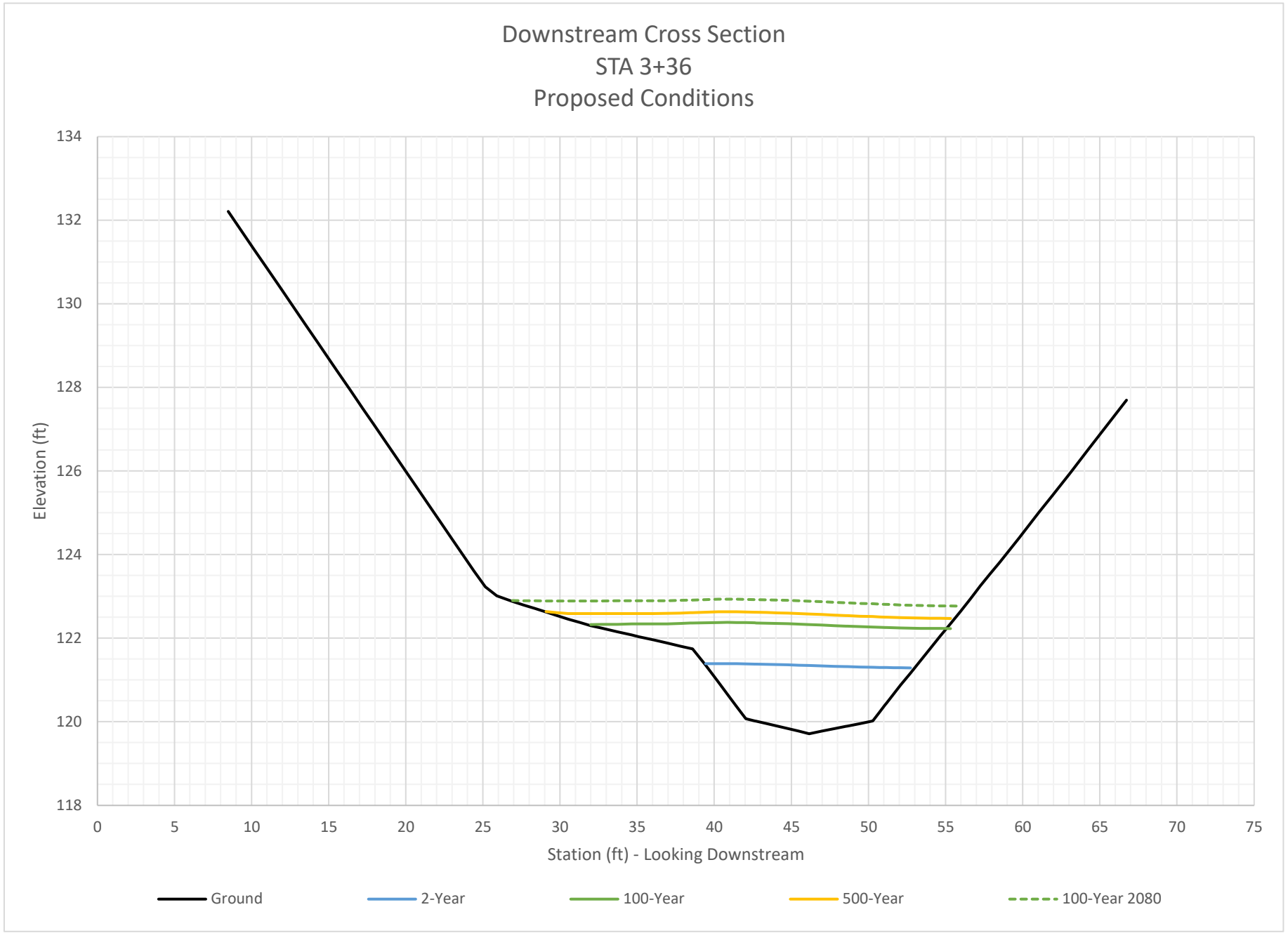

Upstream Cross Section
Station 6+70
Natural Conditions
Elevation (ft)
135
134
133
132
131
130
129
128
127
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

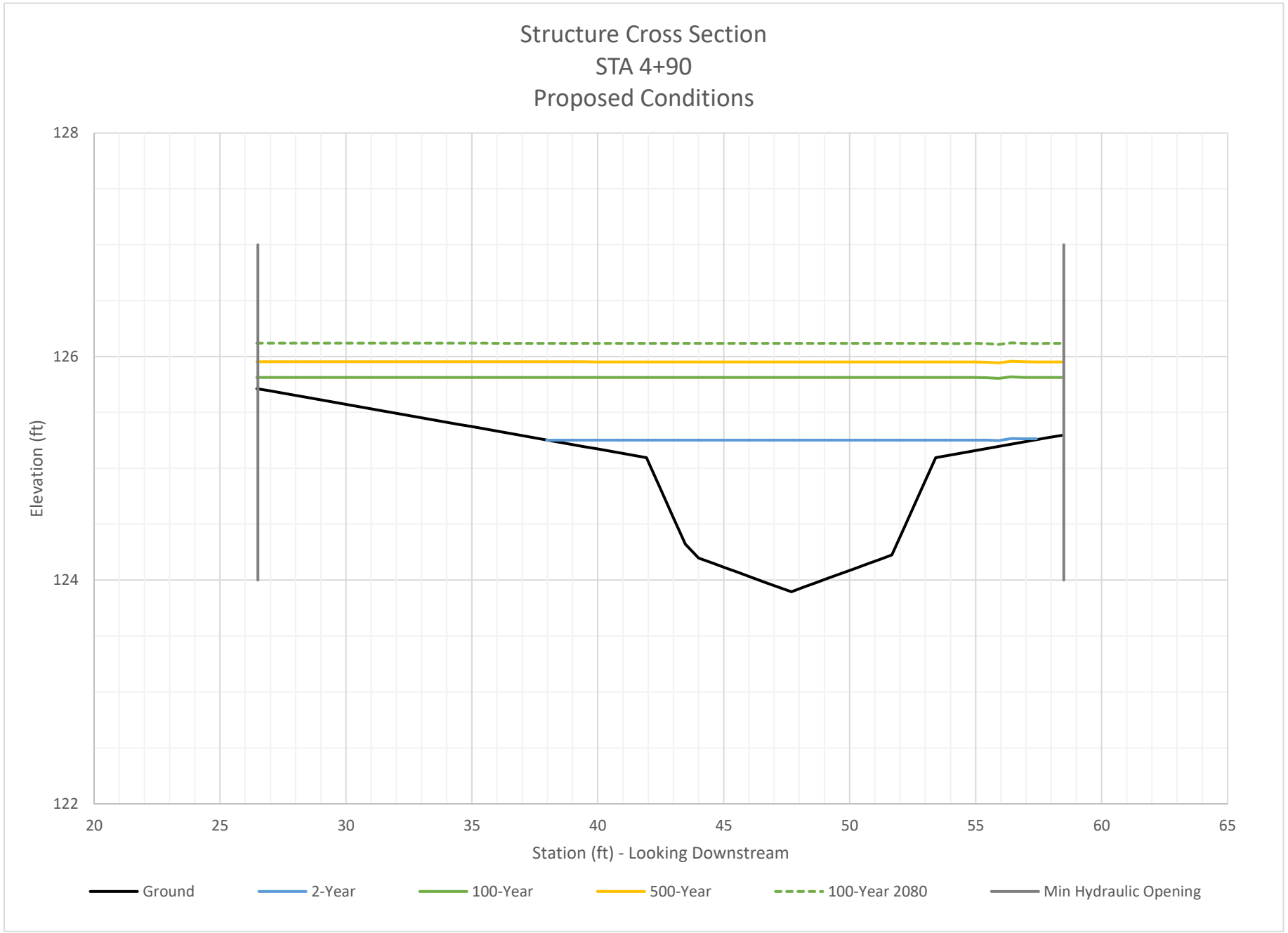

Upstream Cross Section
Station 7+48
Natural Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
129
128
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

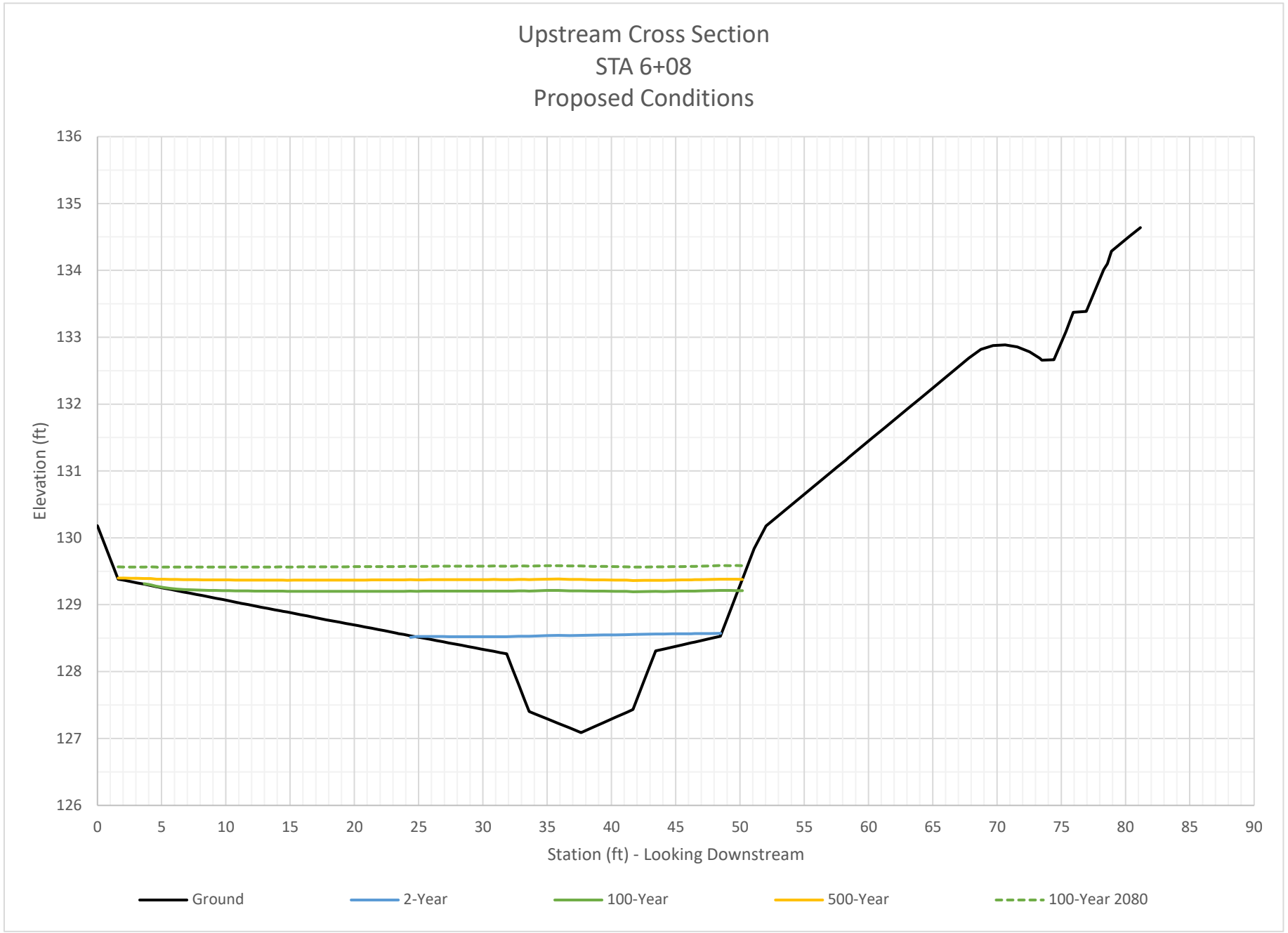

Upstream Cross Section
Station 8+65
Natural Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
0
5
10
15
20
25
30
35
40
45
50
Station (ft) - Looking Downstream
Ground
100-Year
100-Year 2080

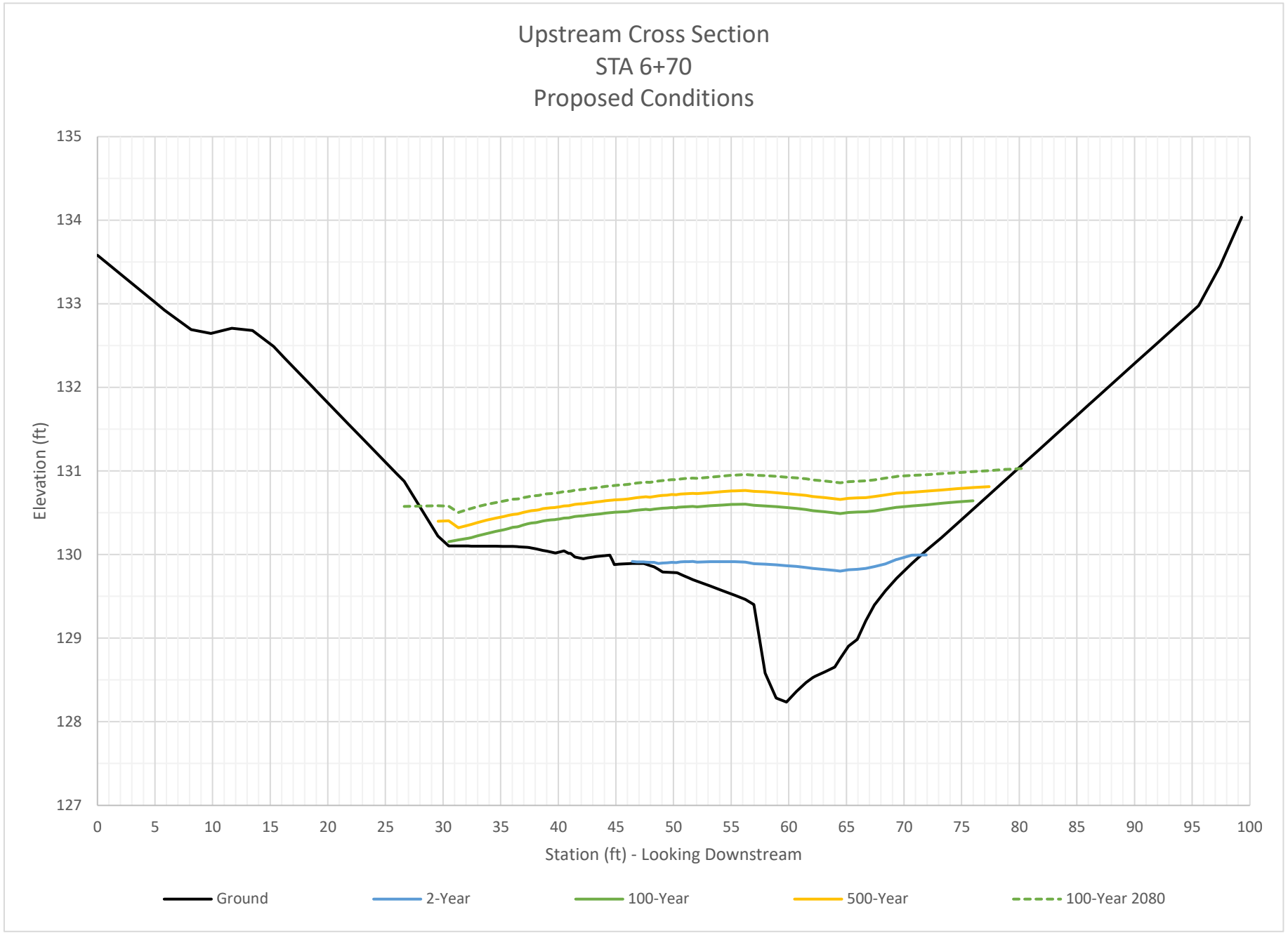

Downstream Cross Section
STA 1+60
Proposed Conditions
Elevation (ft)
126
124
122
120
118
116
114
0
5
10
15
20
25
30
35
40
45
50
55
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080

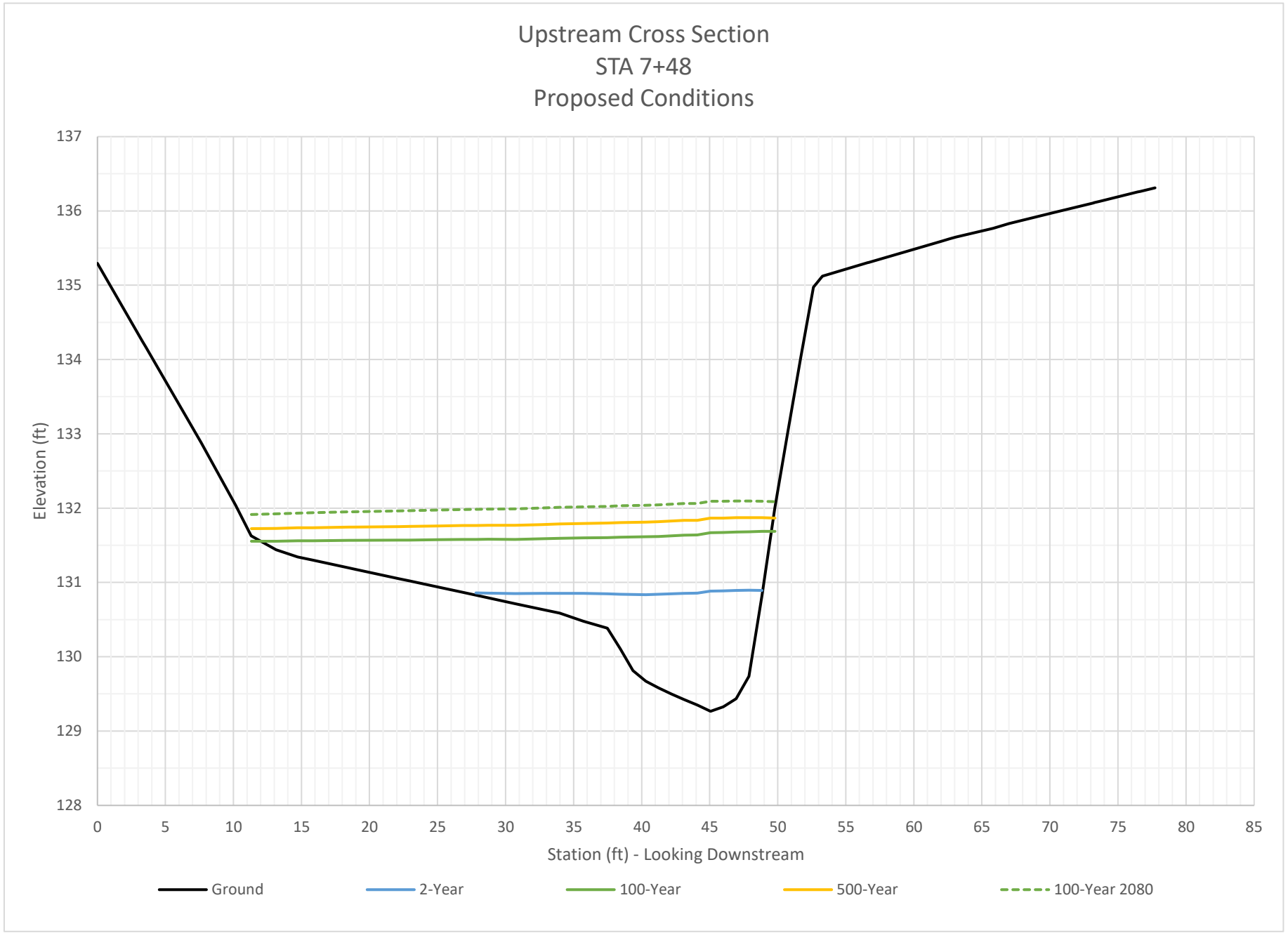

Downstream Cross Section
STA 2+32
Proposed Conditions
Elevation (ft)
130
128
126
124
122
120
118
116
0
5
10
15
20
25
30
35
40
45
50
55
60
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080

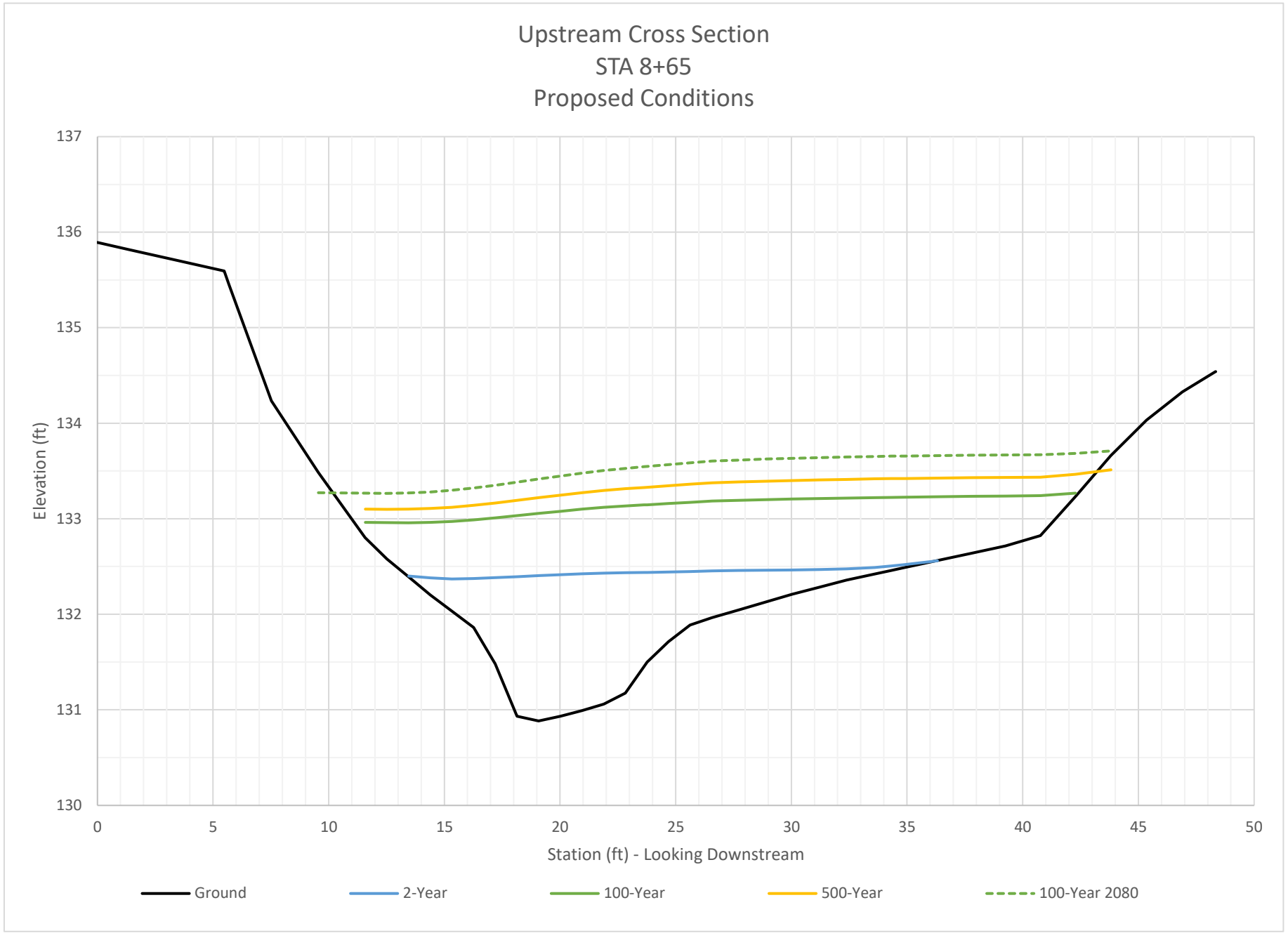

Downstream Cross Section
STA 3+36
Proposed Conditions
Elevation (ft)
134
132
130
128
126
124
122
120
118
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080

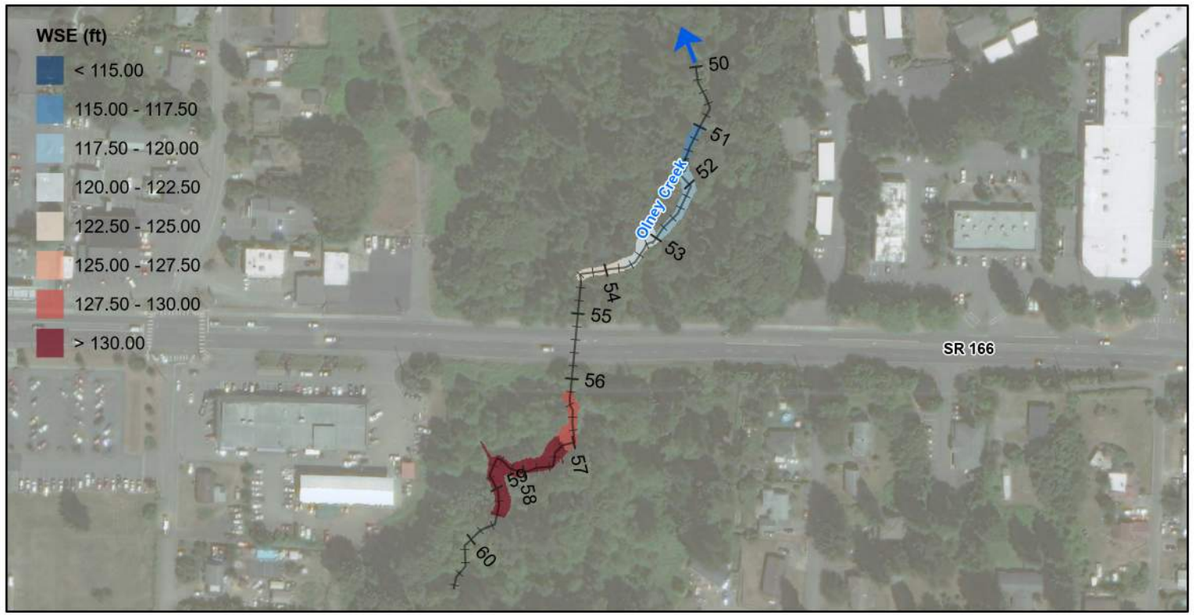

Structure Cross Section
STA 4+90
Proposed Conditions
128
126
124
122
Elevation (ft)
20
25
30
35
40
45
50
55
60
65
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080
Min Hydraulic Opening


Upstream Cross Section
STA 6+08
Proposed Conditions
Elevation (ft)
136
135
134
133
132
131
130
129
128
127
126
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080

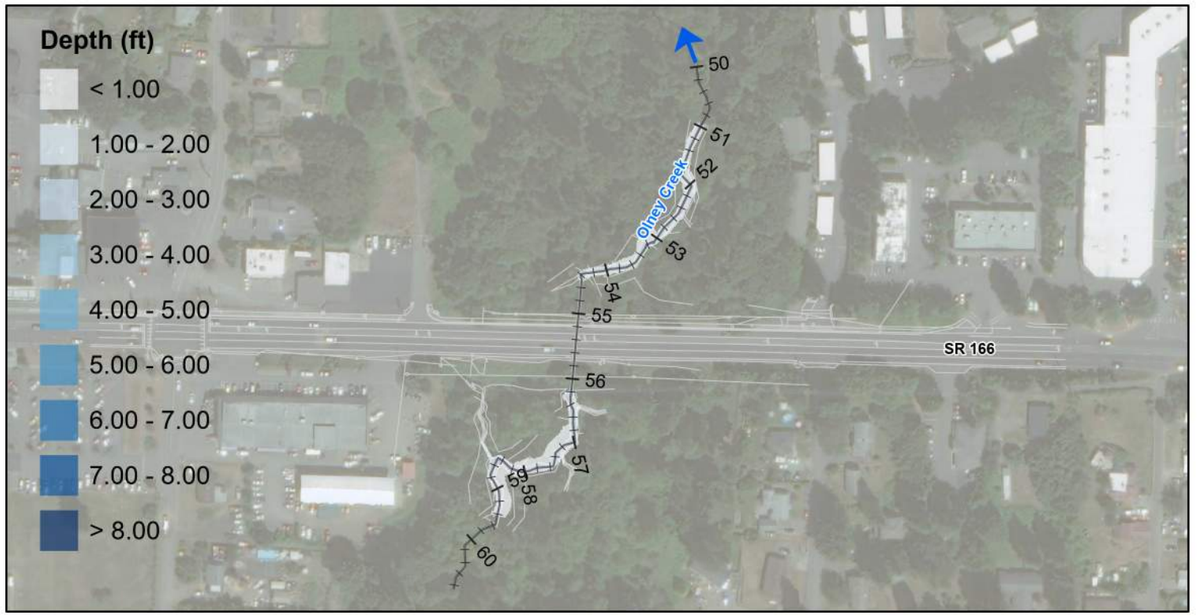

Upstream Cross Section
STA 6+70
Proposed Conditions
Elevation (ft)
135
134
133
132
131
130
129
128
127
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080


Upstream Cross Section
STA 7+48
Proposed Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
129
128
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080

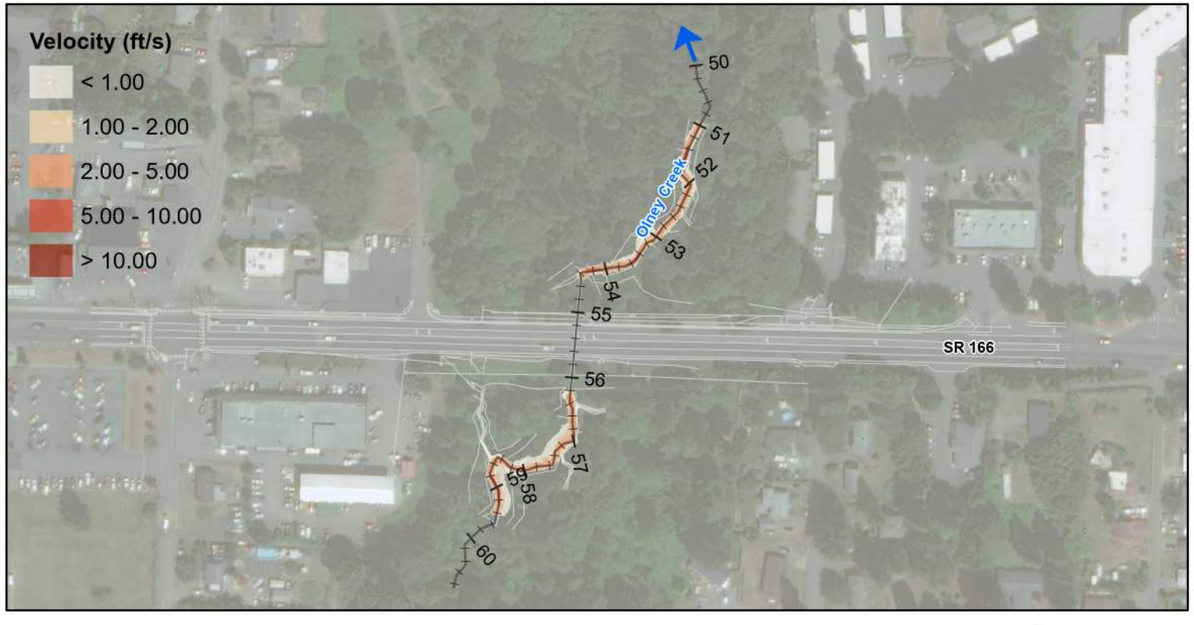

Upstream Cross Section
STA 8+65
Proposed Conditions
Elevation (ft)
137
136
135
134
133
132
131
130
0
5
10
15
20
25
30
35
40
45
50
Station (ft) - Looking Downstream
Ground
2-Year
100-Year
500-Year
100-Year 2080



WATER SURFACE ELEVATION



DEPTH



VELOCITY

SHEAR

N

0 100 200 Feet

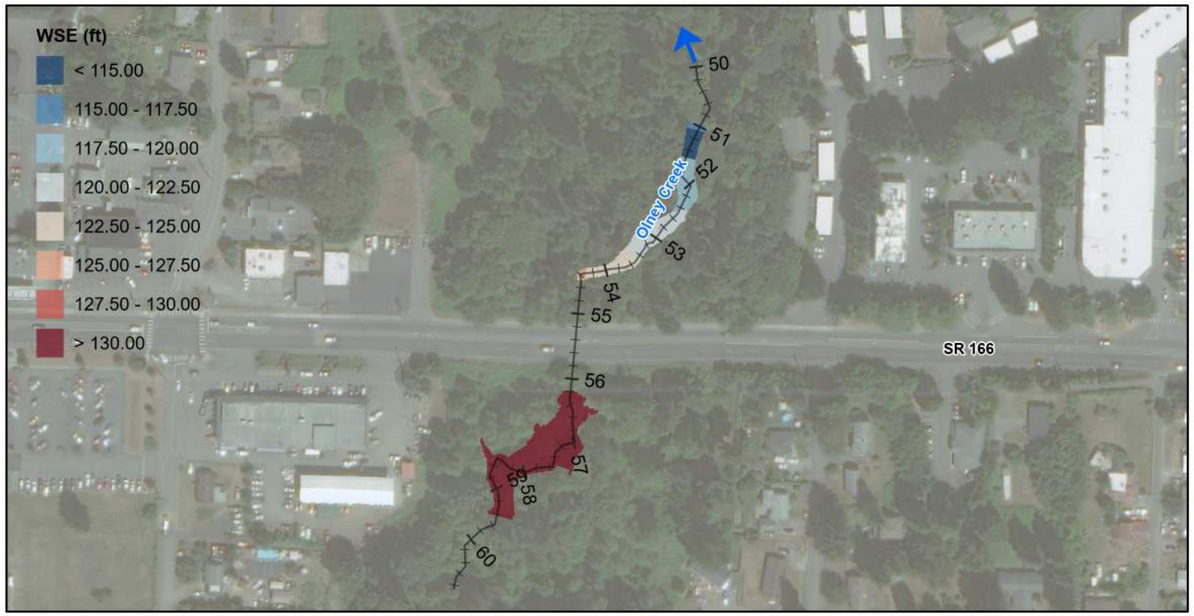
EXISTING CONDITIONS 2-YEAR

HDR

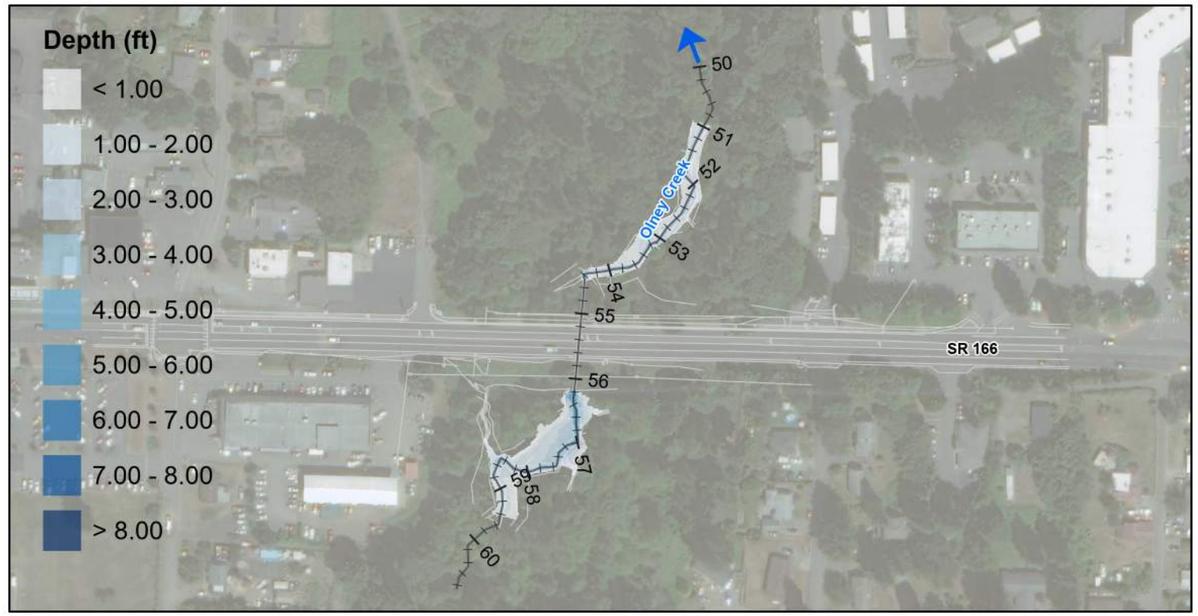
Washington State Department of Transportation

SR 166 OLNEY CREEK

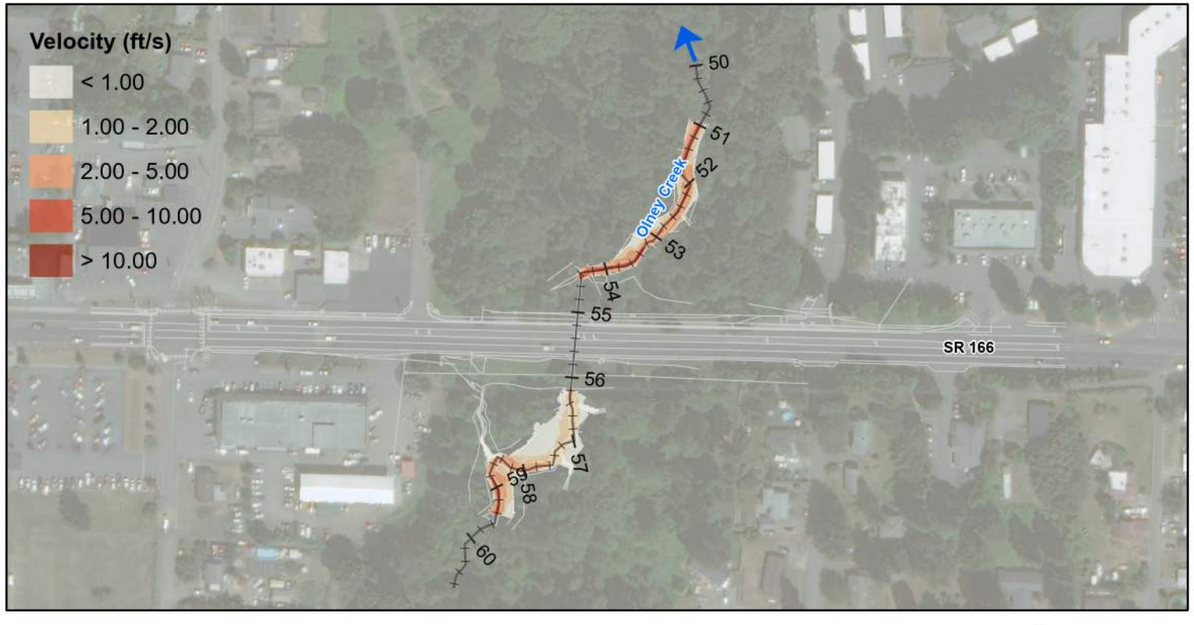
MP 4.52



WATER SURFACE ELEVATION



DEPTH



VELOCITY

SHEAR

N

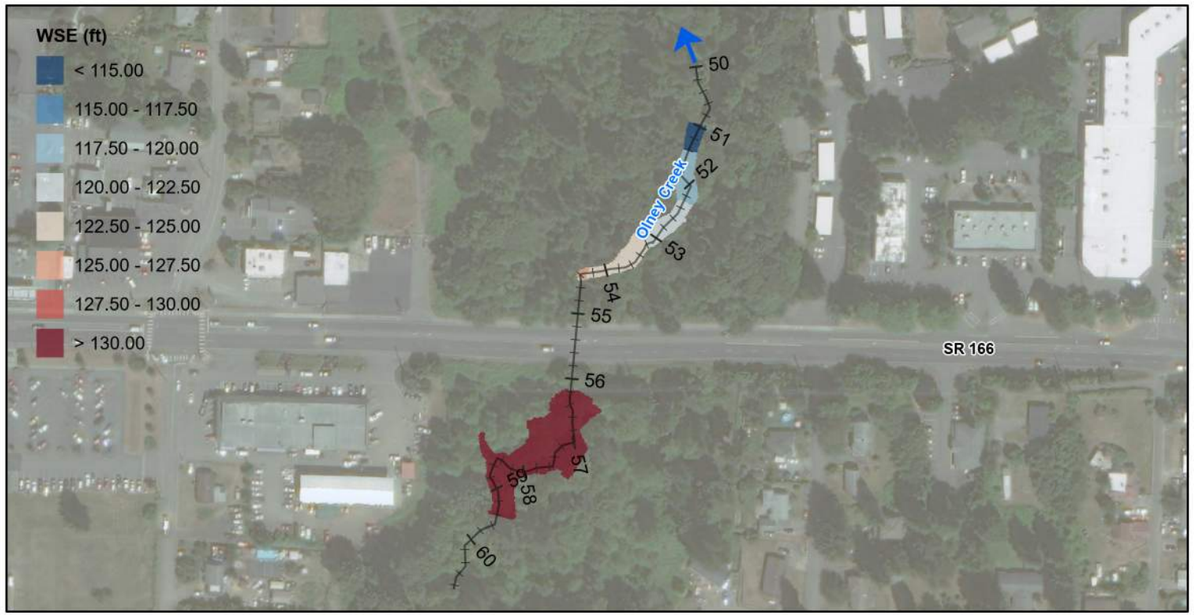
0 100 200 Feet

EXISTING CONDITIONS 100-YEAR

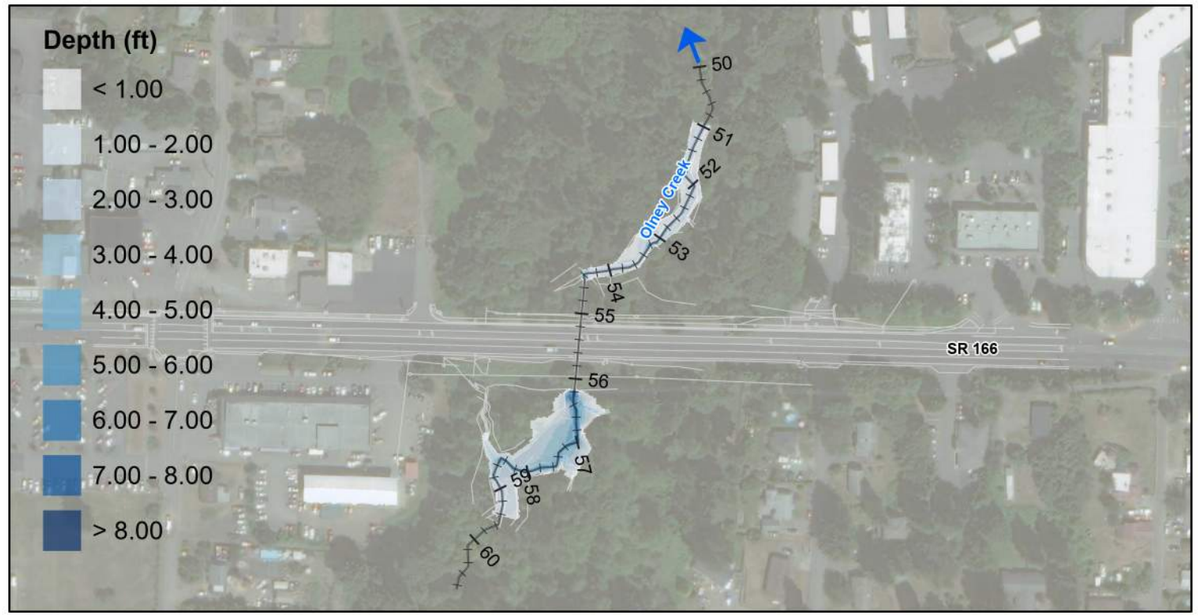
HDR

Washington State Department of Transportation

SR 166 OLNEY CREEK
MP 4.52



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

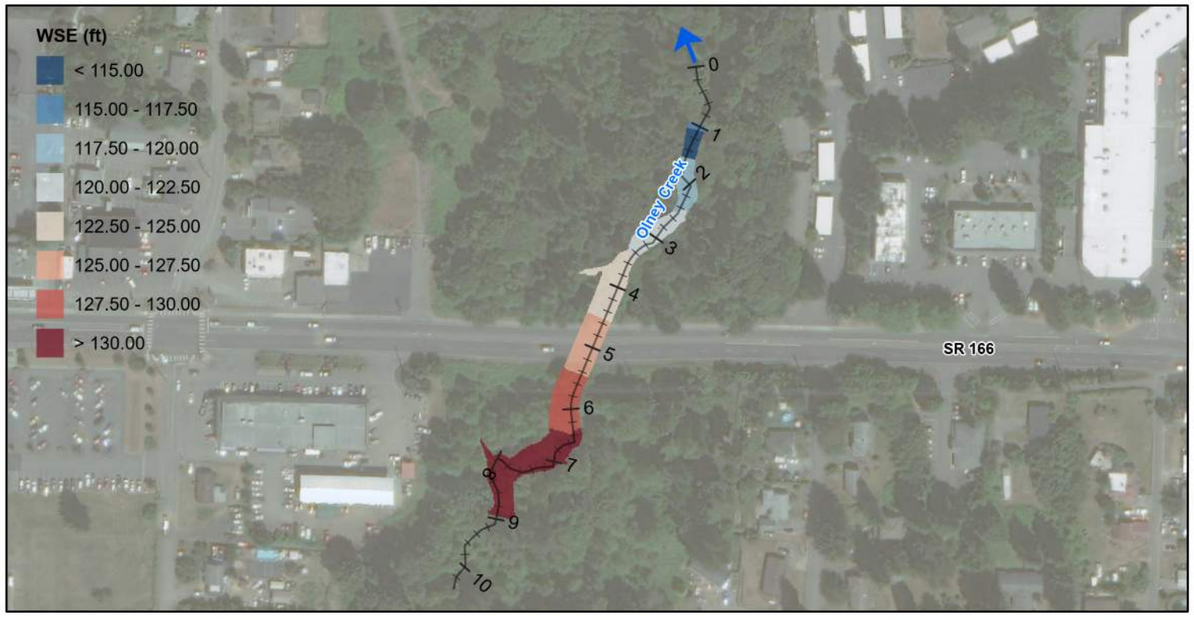
0 100 200 Feet

EXISTING CONDITIONS 500-YEAR

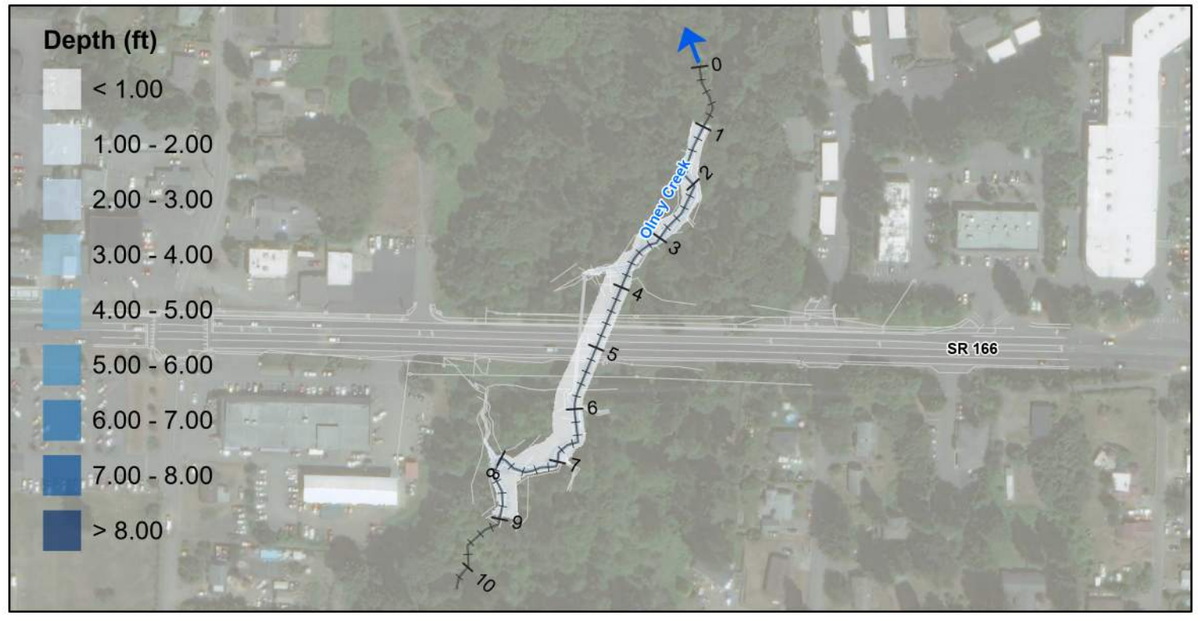
HDR

Washington State Department of Transportation

SR 166 OLNEY CREEK
MP 4.52



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

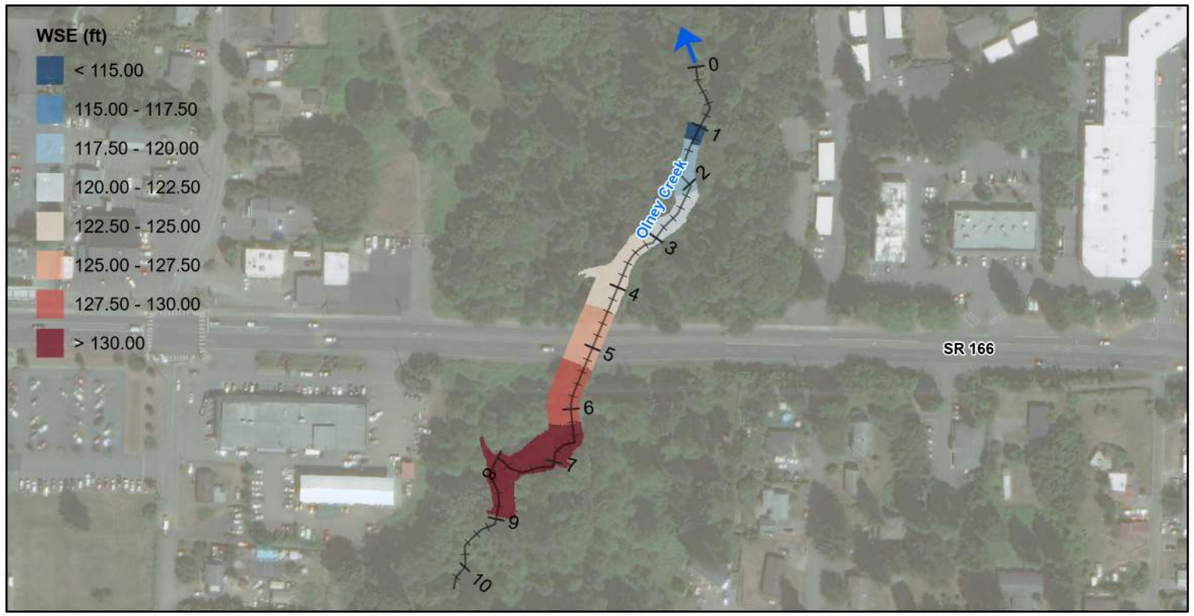
0 100 200 Feet

NATURAL CONDITIONS 100-YEAR

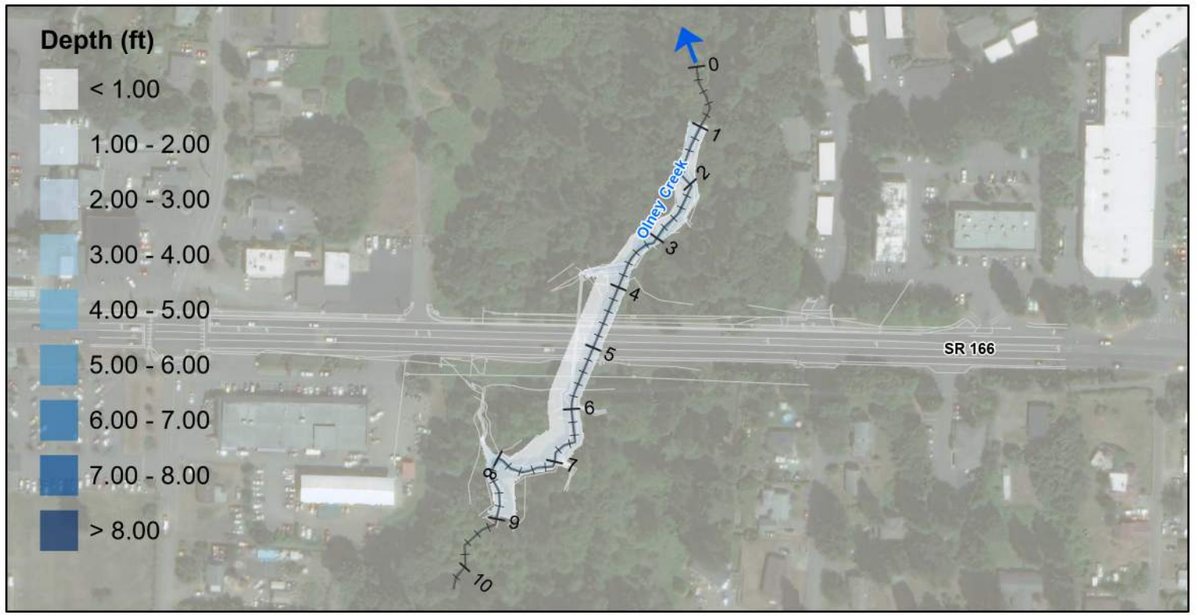
HDR

Washington State Department of Transportation

SR 166 OLNEY CREEK
MP 4.52



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

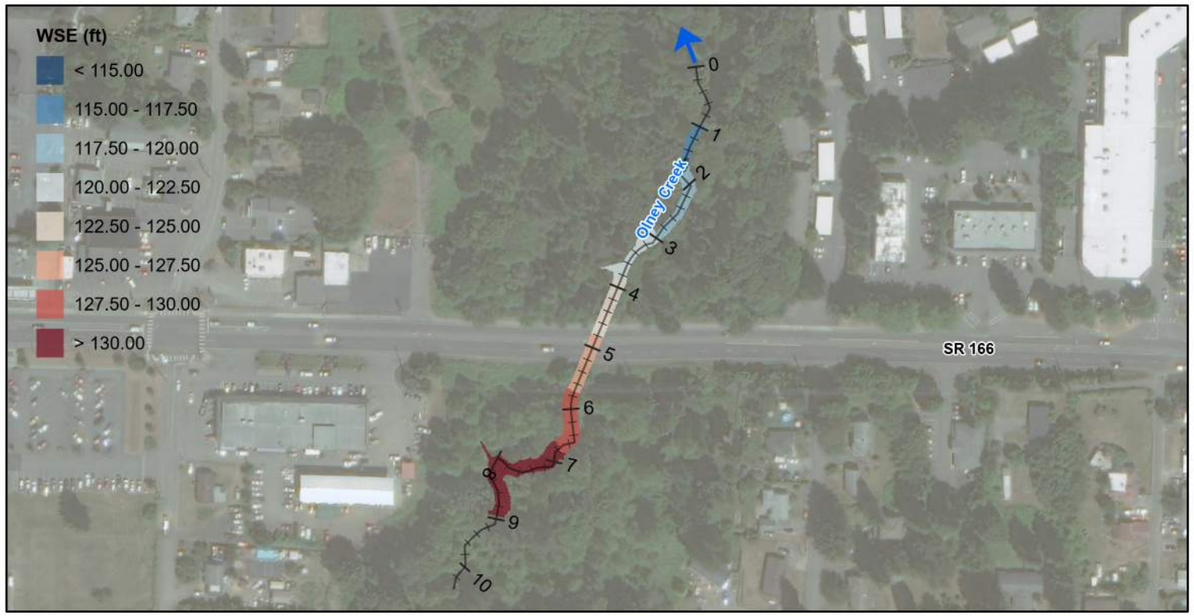
0 100 200 Feet

NATURAL CONDITIONS 100-YEAR 2080

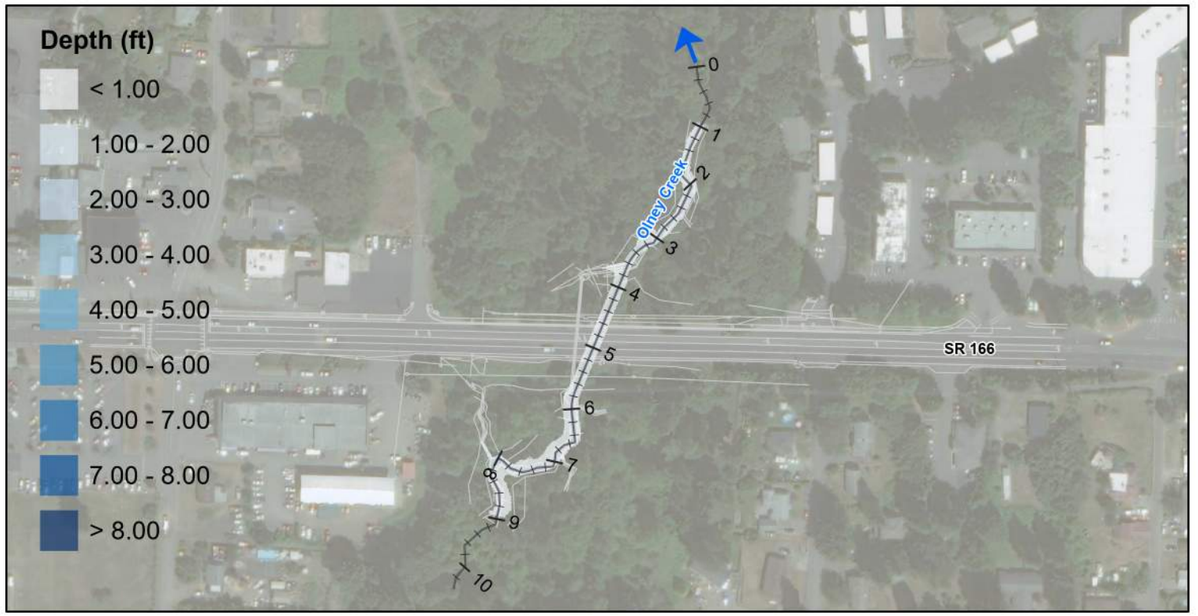
SR 166 OLNEY CREEK
MP 4.52

HDR

Washington State Department of Transportation



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

0 100 200 Feet

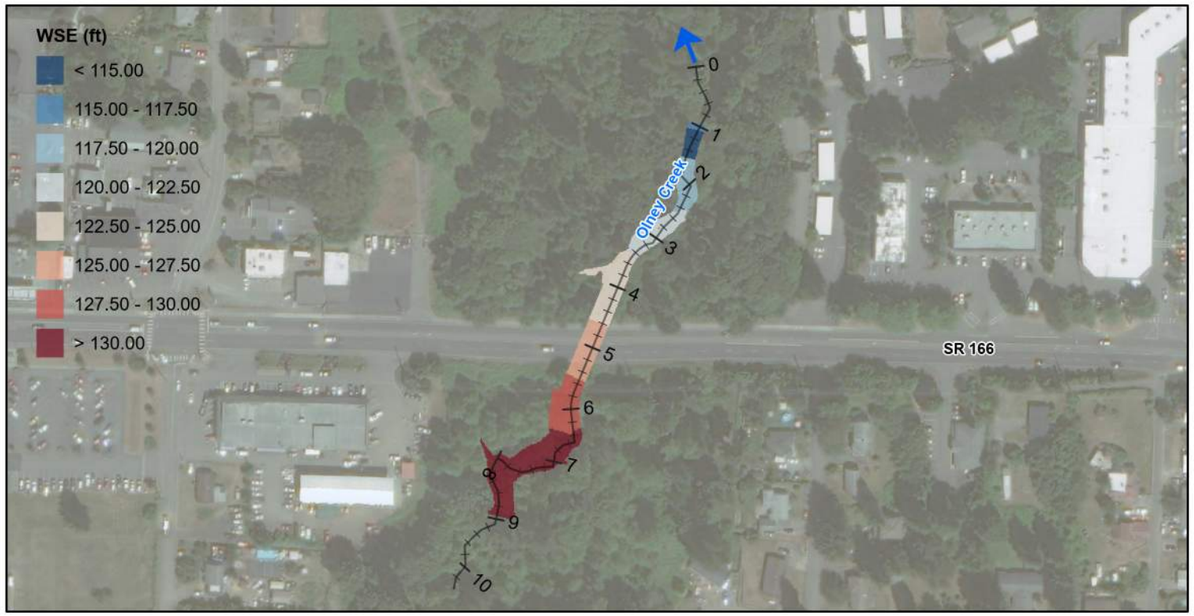
PROPOSED CONDITIONS 2-YEAR

HDR

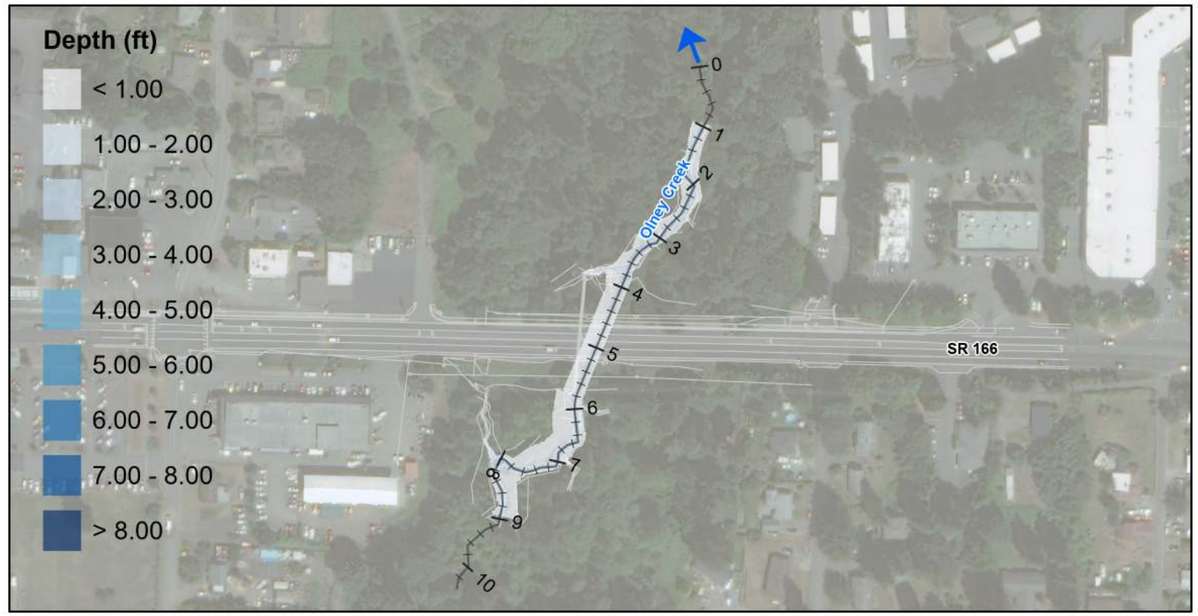
Washington State Department of Transportation

SR 166 OLNEY CREEK

MP 4.52



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

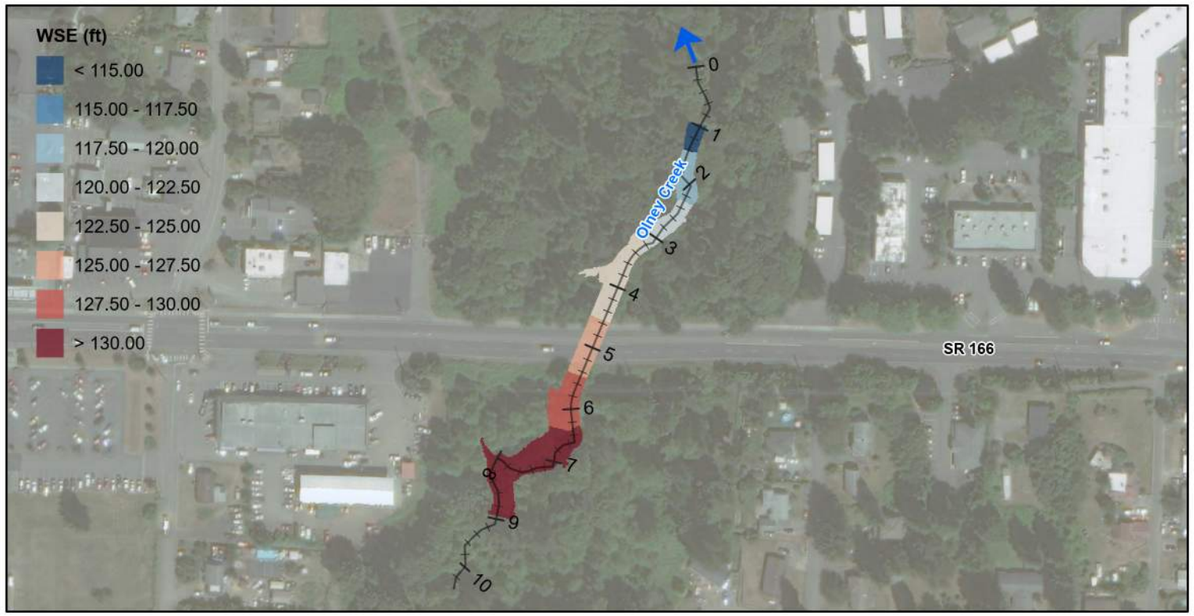
0 100 200 Feet

PROPOSED CONDITIONS 100-YEAR

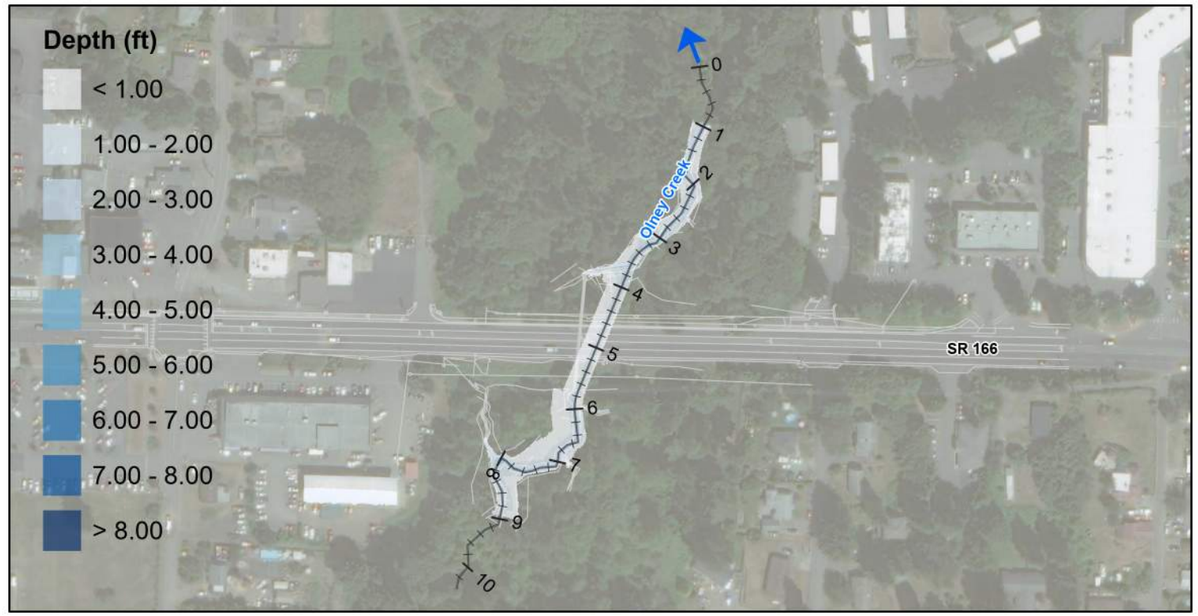
SR 166 OLNEY CREEK
MP 4.52

HDR

Washington State Department of Transportation



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

0 100 200 Feet

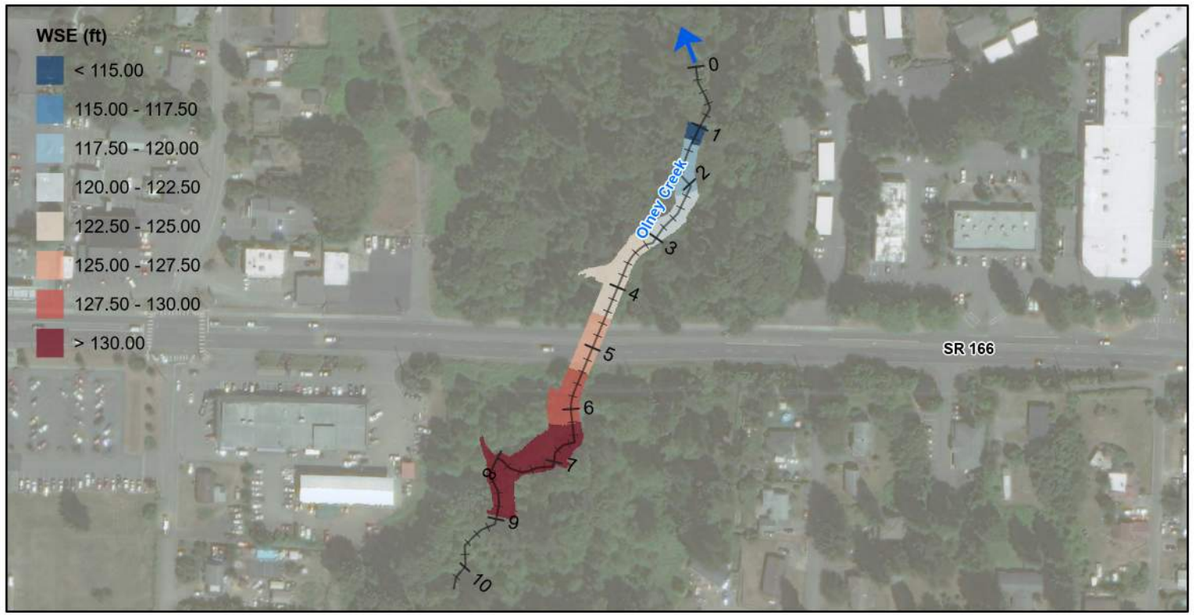
HDR

Washington State Department of Transportation

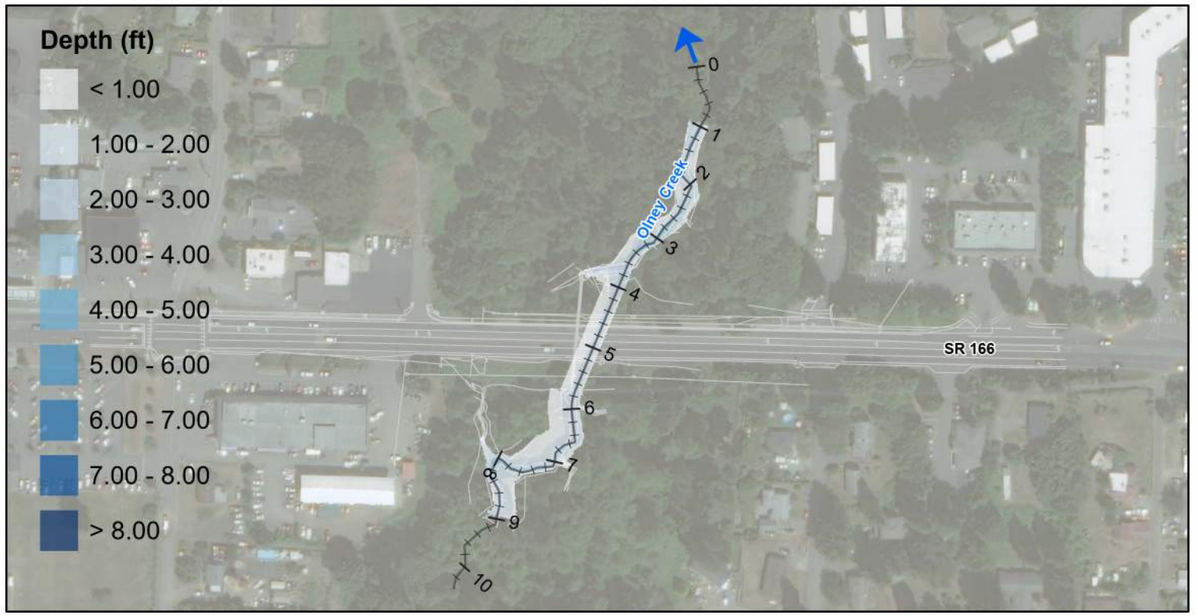
PROPOSED CONDITIONS 500-YEAR

SR 166 OLNEY CREEK

MP 4.52



WATER SURFACE ELEVATION



DEPTH

VELOCITY

SHEAR

N

0 100 200 Feet

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Washington State Department of Transportation

PROPOSED CONDITIONS 100-YEAR 2080

SR 166 OLNEY CREEK
MP 4.52

Appendix D: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	**WSDOT SR 166 MP 4.52**
By:	**Jeff Price**

Observed Streambed Material				
Location:	Reference Reach (Cumulative)			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.25	0.08	0.04	0.02
in	3.0	0.9	0.5	0.3
mm	76	24	12.7	6.8

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				100.0
2.5	63.5	100	65	54	37	32	28				100.0
2.0	50.8	80	50	45	29	25	22				80.0
1.5	38.1	73	35	32	21	18	16				72.5
1.0	25.4	65	20	18	13	12	11				65.0
0.75	19.1	50	5	5	5	5	5				50.0
0.187	4.75	35									35.0
No. 40 =	0.425	16									16.0
No. 200 =	0.0750	7									7.0
% per category		100	0	0	0	0	0	0	0	0	--> 100%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

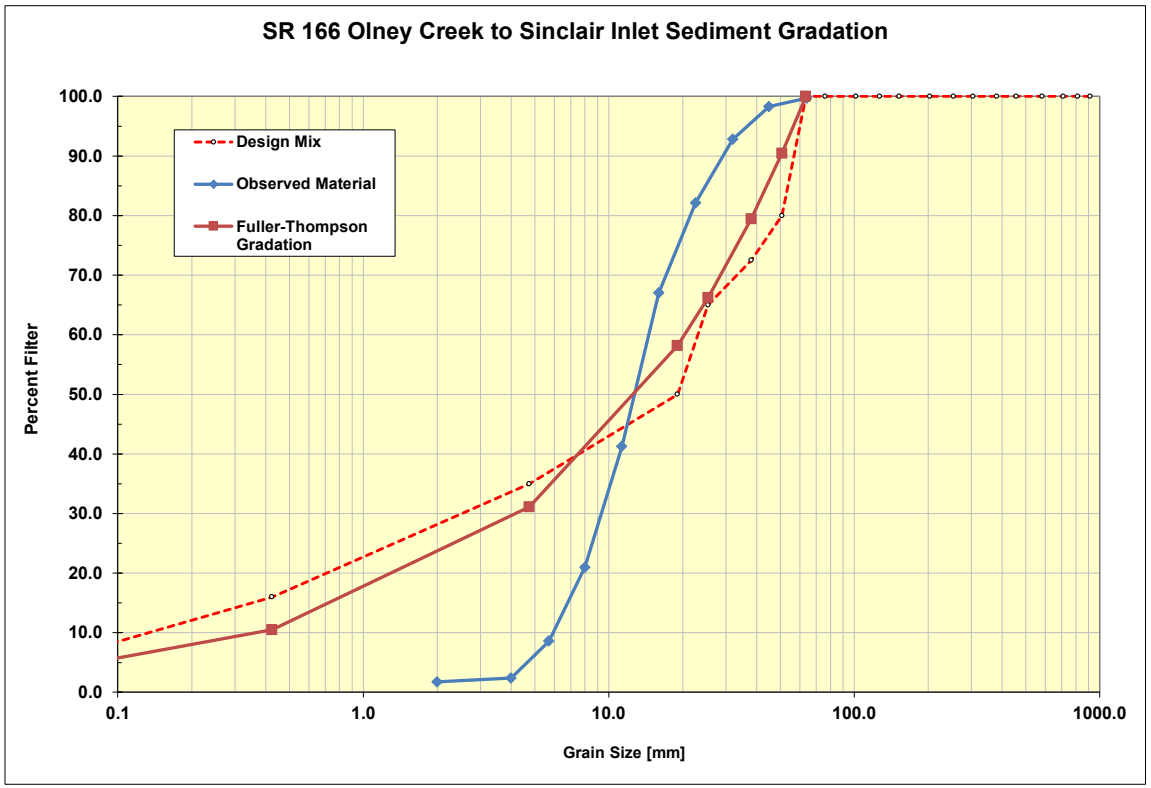
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.047	dimensionless Shields parameter for D50

Flow	2-YR (54.0 cfs)	100-YR (134.4 cfs)	100-YR CC (203.5 cfs	500-YR (163.9 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.6	2.4	2.7	2.9
τ_{ci}				
0.96	Motion	Motion	Motion	Motion
0.93	Motion	Motion	Motion	Motion
0.89	Motion	Motion	Motion	Motion
0.84	Motion	Motion	Motion	Motion
0.78	Motion	Motion	Motion	Motion
0.74	Motion	Motion	Motion	Motion
0.69	Motion	Motion	Motion	Motion
0.66	Motion	Motion	Motion	Motion
0.61	Motion	Motion	Motion	Motion
0.56	Motion	Motion	Motion	Motion
0.53	Motion	Motion	Motion	Motion
0.50	Motion	Motion	Motion	Motion
0.46	Motion	Motion	Motion	Motion
0.43	Motion	Motion	Motion	Motion
0.40	Motion	Motion	Motion	Motion
0.37	Motion	Motion	Motion	Motion
0.33	Motion	Motion	Motion	Motion
0.30	Motion	Motion	Motion	Motion
0.20	Motion	Motion	Motion	Motion

Mix Size Interpolation	**D95**	**D84**	**D50**	**D35**	**D16**
	95	84	50	35	16
(mm)	**60**	**53**	**19**	**5**	**0**
(inches)	**2.4**	**2.1**	**0.8**	**0.2**	**0.0**
(feet)	**0.20**	**0.17**	**0.06**	**0.02**	**0.00**

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



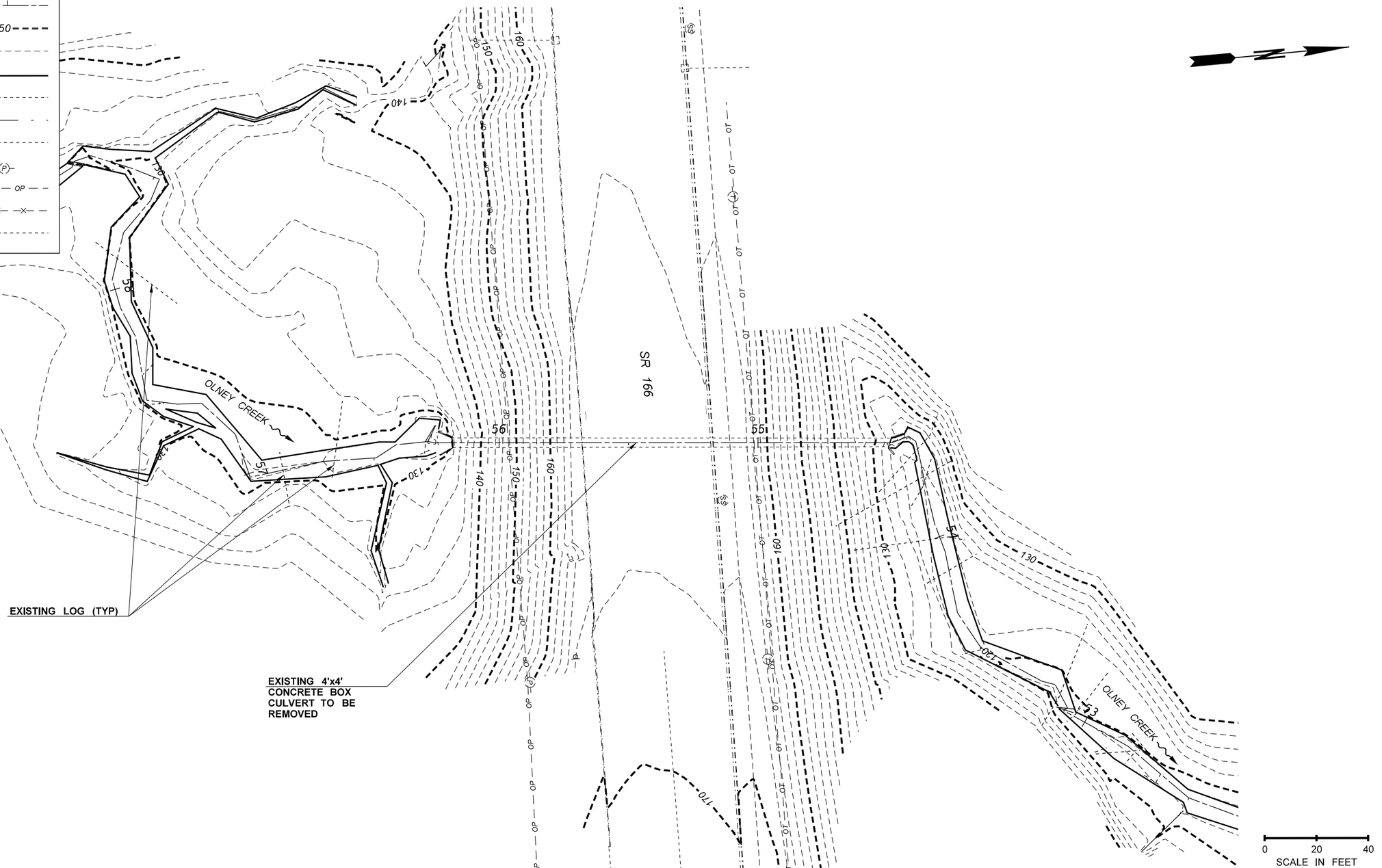
Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix E: Stream Plan Sheets, Profile, Details

T.24N. R.1E. W.M.

LEGEND

EXISTING STREAM ALIGNMENT	56
EXISTING INDEX CONTOUR	250
EXISTING INTERMEDIATE CONTOUR	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
EXISTING CULVERT	
EXISTING POWER POLE	P
EXISTING OVERHEAD POWER LINE	OP
EXISTING FENCE	
EXISTING LOG	



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DESIGNED BY	D. MINNER				CONTRACT NO.		LOCATION NO. XL_____
ENTERED BY	M. KEILBART						
CHECKED BY	J. HEILMAN						
PROJ. ENGR.	J. METTLER						
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY			

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

HDR

SR 166 MP 4.52
OLNEY CREEK
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

T.24N. R.1E. W.M.

LEGEND

- NEW STREAM ALIGNMENT
- EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- STREAM SCALABLE EDGE
- EXISTING EDGE OF PAVEMENT
- EXISTING DITCH
- EXISTING CULVERT
- EXISTING POWER POLE
- EXISTING OVERHEAD POWER LINE
- EXISTING FENCE
- EXISTING LOG
- CUT LINE
- FILL LINE

EXISTING LOG (TYP)

BEGIN CHANNEL GRADING OC 6+36.65

TRANSITION TO MATCH EXISTING CHANNEL OC 6+11.65 TO 6+36.65

BEGIN STRUCTURE OC 5+70.00

32' MINIMUM HYDRAULIC OPENING (SEE NOTE 2)

PROPOSED STRUCTURE (SEE NOTE 1)

TRANSITION PROPOSED CHANNEL GRADING TO PROMOTE DRAINAGE OF EXISTING ABANDONED CHANNEL

END STRUCTURE OC 3+96.0

TRANSITION TO MATCH EXISTING CHANNEL OC 3+23.45 TO 3+48.45

BEGIN CHANNEL GRADING OC 3+23.45

SR 166

OLNEY CREEK

OC LINE

2:1 SEE NOTE 3

2:1 / 25:1 / 12:1 / 12:1 / 25:1 / 2:1

NOTES:

1. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATION PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED AT LATER PHASE OF DESIGN.
2. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN IN PLAN.
3. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.

0 20 40
SCALE IN FEET

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	D. MINNER				CONTRACT NO.		LOCATION NO. XL_____
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CHECKED BY	J. HEILMAN						
PROJ. ENGR.							
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY			

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

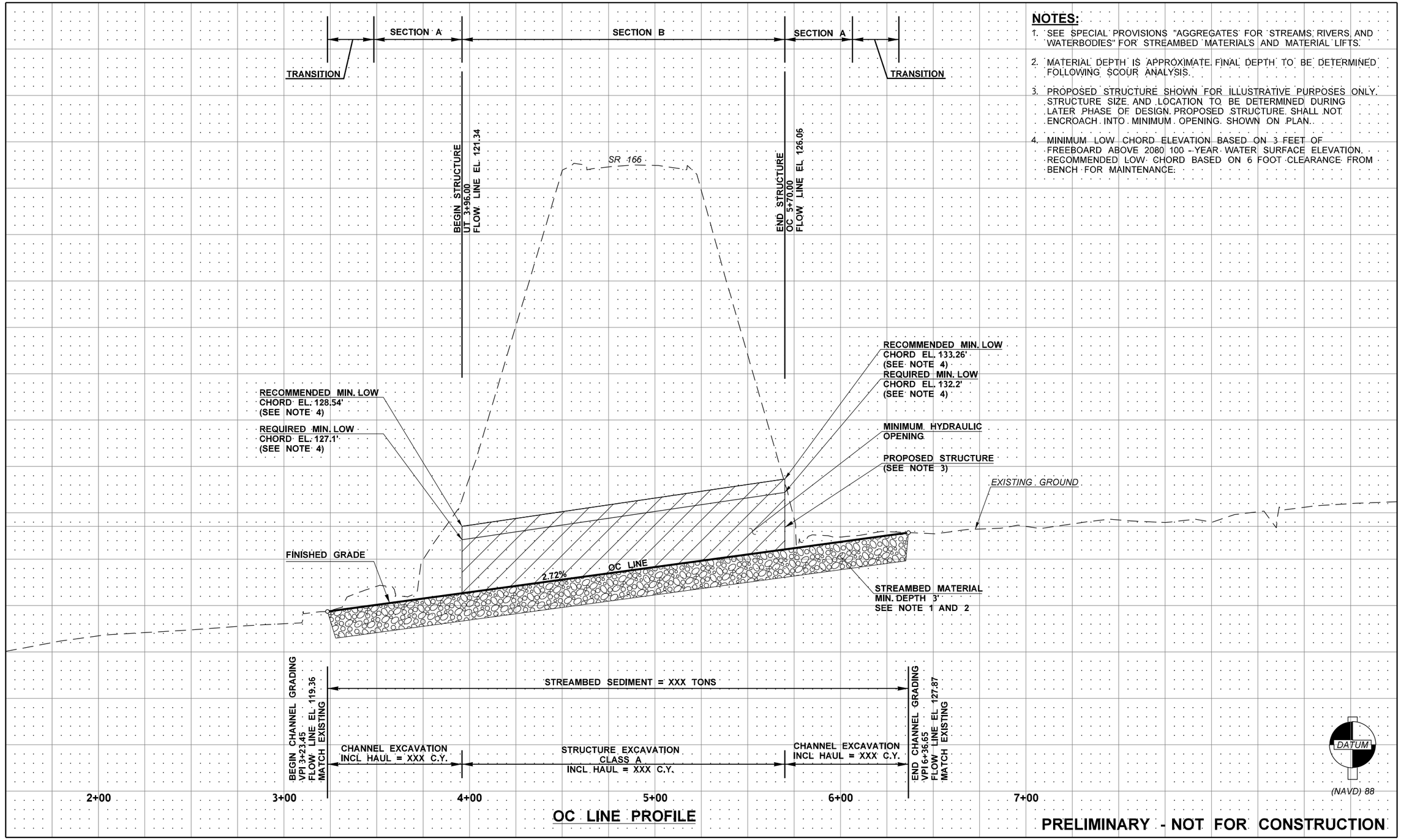
HDR

SR 166 MP 4.52
OLNEY CREEK
FISH BARRIER REMOVAL

STREAM PLAN

PLAN REF NO CR1

SHEET 2 OF 4 SHEETS



NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS AND WATERBODIES" FOR STREAMBED MATERIALS AND MATERIAL LIFTS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE SIZE AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.
4. MINIMUM LOW CHORD ELEVATION BASED ON 3 FEET OF FREEBOARD ABOVE 2080 100 - YEAR WATER SURFACE ELEVATION. RECOMMENDED LOW CHORD BASED ON 6 FOOT CLEARANCE FROM BENCH FOR MAINTENANCE.

OC LINE PROFILE

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	D. MINNER
ENTERED BY	M. KEILBART
CHECKED BY	J. HEILMAN
PROJ. ENGR.	
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO. 10 | STATE WASH
JOB NUMBER XXXXX
CONTRACT NO.
FED.AID PROJ.NO.
LOCATION NO. XL_____

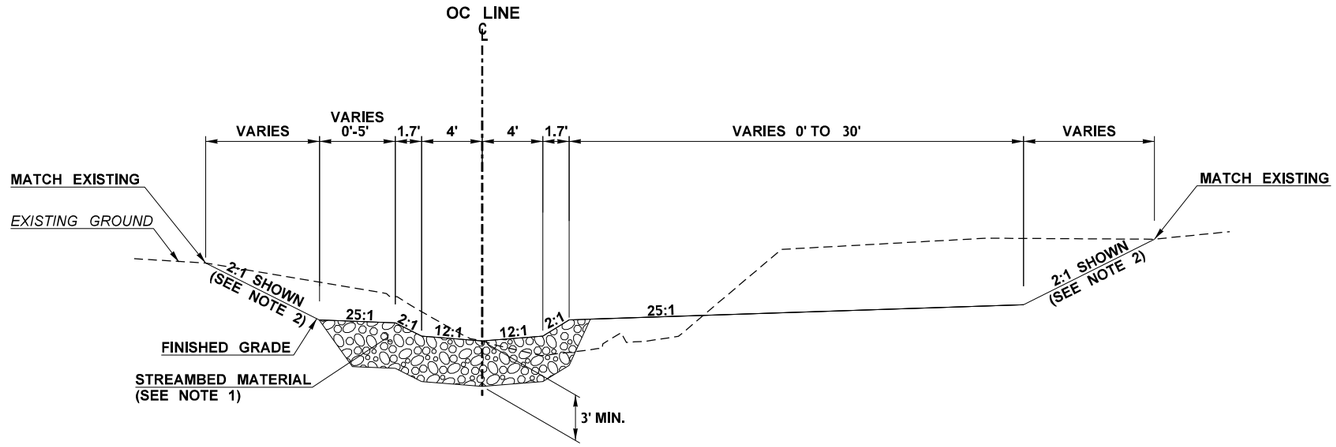
P.E. STAMP BOX — DATE
P.E. STAMP BOX — DATE

Washington State Department of Transportation
HDR

SR 166 MP 4.52
OLNEY CREEK
FISH BARRIER REMOVAL

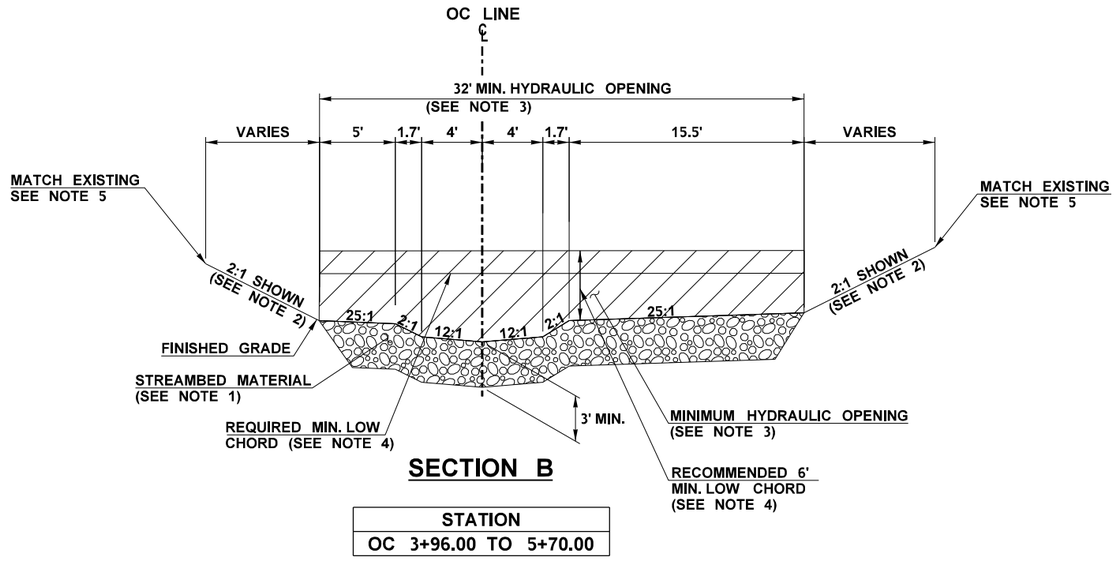
STREAM PROFILE

PLAN REF. NO. CP1
SHEET 3 OF 4 SHEETS



SECTION A

STATION
OC 5+70 TO 6+36.65
3+23.45 TO 3+96.00



SECTION B

STATION
OC 3+96.00 TO 5+70.00

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. SLOPES SHOWN OUTSIDE HYDRAULIC OPENING ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOLOGICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING ON PLAN.
4. SEE SHEET CP1 FOR MINIMUM LOW CHORD ELEVATION THROUGHOUT STRUCTURE.
5. EXISTING GRADE IS TO HIGH AND OUTSIDE OF SECTION SCALE. SEE PLAN CR1 FOR CUT FILL LINE.

PRELIMINARY - NOT FOR CONSTRUCTION

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PROJ. ENGR.							
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY			

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

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SR 166 MP 4.52
OLNEY CREEK
FISH BARRIER REMOVAL

STREAM DETAILS

PLAN REF NO CD1

SHEET 4 OF 4 SHEETS

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Appendix F: Scour Calculations

This appendix was not used because it is used for the FHD Report, not the PHD Report.

Appendix G: Manning's Calculations

This appendix was not used because Manning's calculations were not needed to support the values chosen.

Appendix H: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

culvert

State Route# & MP	***SR166 MP4.52***		**Key piece volume**	***1.310***	*yd³*
Stream name	*Olney Creek*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*313*	*ft*	**Total wood vol./ft**	***0.3948***	*yd³ /ft stream*
Bankfull width	*13*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd³ /log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd³)*
A	2.00	*30*	3.49	**yes**	yes	10	34.91
B	2.00	*25*	2.91	**yes**	yes	9	26.18
C	1.50	*20*	1.31	**yes**	no	7	9.16
D	1	*15*	0.44	**yes**	no	10	4.36
E			0.00				0.00
F			0.00				0.00
G			0.00				0.00
H			0.00				0.00
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd³)**
Design	19	36	74.6
Targets	**10**	**36**	**123.6**

WSDOT Large Woody Material for stream restoration metrics calculator

bridge

State Route# & MP	***SR166 MP4.52***		**Key piece volume**	***1.310***	*yd³*
Stream name	*Olney Creek*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*313*	*ft*	**Total wood vol./ft**	***0.3948***	*yd³ /ft stream*
Bankfull width	*13*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd³ /log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd³)*
A	2.00	*30*	3.49	**yes**	yes	14	48.87
B	2.00	*25*	2.91	**yes**	yes	11	32.00
C	1.50	*20*	1.31	**yes**	no	9	11.78
D	1	*15*	0.44	**yes**	no	10	4.36
E			0.00				0.00
F			0.00				0.00
G			0.00				0.00
H			0.00				0.00
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd³)**
Design	25	44	97.0
Targets	**10**	**36**	**123.6**

Appendix I: Future Projects for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 15.0201 0.90

Stream Name: Olney Creek

Drainage Area: 881 ac

Projected mean percent change in bankfull flow:

2040s: 14.1%

2080s: 18.6%

Projected mean percent change in bankfull width:

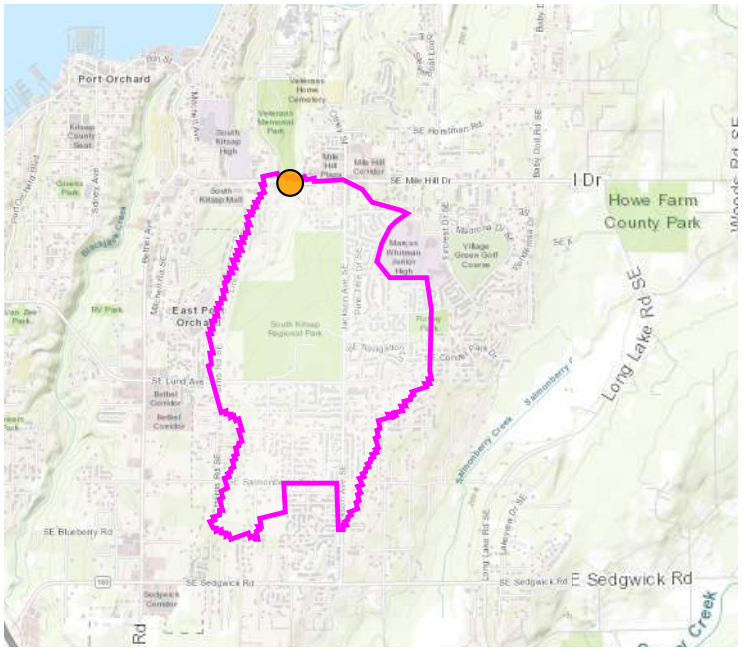
2040s: 6.8%

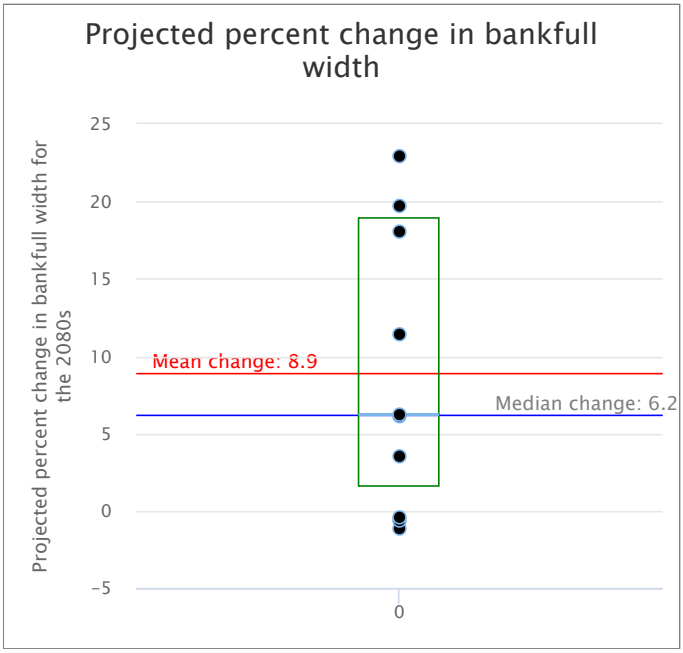
2080s: 8.9%

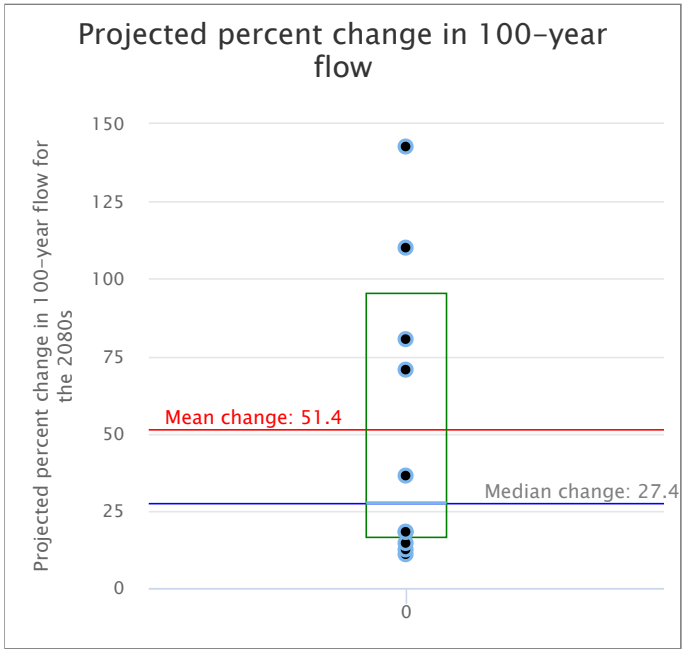
Projected mean percent change in 100-year flood:

2040s: 36.3%

2080s: 51.4%







Black dots are projections from 10 separate models

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